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Measurement Techniques

(The Soviet Journal *Izmeritel'naya Tekhnika* in English Translation)

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SOVIET INSTRUMENTATION AND CONTROL TRANSLATION SERIES

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The original Russian articles are translated by competent technical personnel. The translations are on a cover-to-cover basis, permitting readers to appraise for themselves the scope, status, and importance of the Soviet work.

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Transliteration of the names of Russian authors follows the system known as the British Standard. This system has recently achieved wide adoption in the United Kingdom, and is being adopted in 1959 by a large number of scientific journals in the United States.

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CONTRIBUTION OF THE METROLOGICAL INSTITUTES AND LABORATORIES

P. P. Arapov

Hall No. 21 of the "Engineering" pavilion contains the products of the institutes and laboratories of the Committee of Standards, Measures and Measuring Instruments in the sphere of metrology and measurement technology.

The exhibited models of measuring instruments and equipment and their artistic presentation have been considerably improved as compared with previous years.

The role of the standard and precision measuring instruments in the national economy of the USSR is portrayed on these stands. Without a wide application of these instruments, the introduction of new techniques, group mechanization and automation of production and improvements in the quality of production are impossible. By means of standards and precision instruments, standardized and accurate measuring instruments, required in modern production, are provided.

The exhibits are grouped in their spheres of measurements.

The "Linear and angle measurements" section has been supplemented by opticomechanical instruments, instruments for checking gear wheels, instruments and devices for measuring the roughness of metallic surfaces and other instruments.

The VNIIM is exhibiting an interferometer for checking flatness and parallelism type IPP-15, designed to measure deviations from flatness of glass and metallic faces with an error not exceeding 0.05μ and parallelism with an error not exceeding $0.1\ \mu$. The instrument can measure components up to 140 mm in diameter and 170 mm thick.

Flatness is checked by observing with monochromatic light in the field of vision of the instrument equally spaced interference bands, and parallelism, by checking equally inclined interference rings.

The VNIIM photoelectric profilograph FEP-1 is used for determining the roughness of metallic faces by a noncontact method. It is possible with this instrument in addition to measuring roughness of external and internal faces and determining the values of H_{ck} according to GOST 2789-51, also to inspect on the screen of the tube the nature of the microirregularities.

The limits of measurement extend from the 4th to the 13th grade of surface finishes. The length of profile tracing is up to 2 mm. Vertical magnification on the tube screen extends from 5000 to 20000. The horizontal magnification amounts to 100. The minimum internal diameter of a measured detail is 40 mm.

Not a few of the instruments exhibited in this section have been developed by the Interchangeability Bureau.

Induction Profilograph PCh-4 for measuring roughness of metallic faces. The instrument has a transducer with a diamond feeler, actuated by a mechanical drive or by hand, and a calibrated amplifier with a pointer indicator. The instrument scale is calibrated in values of H_{ck} or R_a.

The limits of measurement extend from grade 5 to 12 of surface finishes according to GOST 2783-51.

The error of the instrument when working without a motor drive does not exceed $\pm$ 25%.

Fig. 1.

When this instrument is generally adopted for factory checking of surface roughness, objective inspection will be introduced without using comparison standards.

Instrument type BV-890 for checking circular pitches of gear wheels is used for checking differences in adjacent circular pitches or the aggregate error of circular pitches in large precision gear-wheels with a module of 2 to 6 mm.

The instrument posesses a high degree of accuracy and provides measurements of gear wheels up to the 4th grade of accuracy according to GOST 1643-56.

Group pitch-measuring device type BV-990 for checking cylindrical gear-wheels is used for determining the aggregate error of circular pitches in large high precision cylindrical gear-wheels with a module of 1 to 8 mm and diameter of 250 to 4000 mm.

The instrument is universal, possesses high accuracy and raises 3 to 5 times the inspection productivity of gear wheels up to the 4th grade of accuracy according to GOST 1643-56.

Collet-type inside calipers BV-1024 are designed for measuring small diameters between 3 and 3.75 mm. The instrument has a collet and a measuring head in the form of a micrometer of the LIZ plant.

Its error of measurement does not exceed ± 0.01 mm. Owing to its high precision the instrument doubles the productivity of the inspector's work.

Pneumatic recording instrument BV-1042 (Fig. 1) keeps a continuous record of measurements. The instrument can record variations of a single dimension or add and subtract several dimensions. Electrical contacts included in the instrument provide the facility for using it in automatic control systems.

The width of the recording chart is 120 mm. Its speed is 200 mm/min.

Electrical-contact graduated amplitude transducer type BV-1045 is used for automatically checking deviations of details from a set geometrical form or mutual position of their surfaces and for grading the details into "good" and "reject".

The instrument has small external dimensions (102 × 53 × 15 mm), is simple to adjust, highly productive, making 3000 to 5000 measurements per shift, and is very convenient for checking geometrical shapes of details (determining whether it is oval, has the required faces, etc).

The limit of measurable deviations is 0.2 mm. The error does not exceed ± 0.5μ.

Inductive recorder type BV-1010 is used mainly for recording small displacements, which characterize the accuracy of kinematic systems of various machines and mechanisms. The instrument has a small-size induction transducer and an electronic unit with a device recording on a rectangular coordinate chart.

The scale of recording is vertically 500:1 or 5000:1. The width of the chart is 210 mm.

Errors of recording are ± 0.5 and ± 4 μ according to the scale being used.

This recorder provides automation of checking the kinematic accuracy of mechanisms and considerably increases its productivity.

VNIIK is exhibiting a probing effort indicator designed for measuring the probing effort of feeler profile-meters and profilographs, which determine the roughness of metallic surfaces.

The measuring range is from 0.05 to 5 g-wt.

The application of this instrument increases the quality of surface roughness checking.

The VNIIK equipment for determining the radius of curvature of needles is designed for checking the basic elements of feeler profile-meters and consists of a microscope, a table with a collet clamp for diamond needles, photographic attachment and an illuminating device with a transformer.

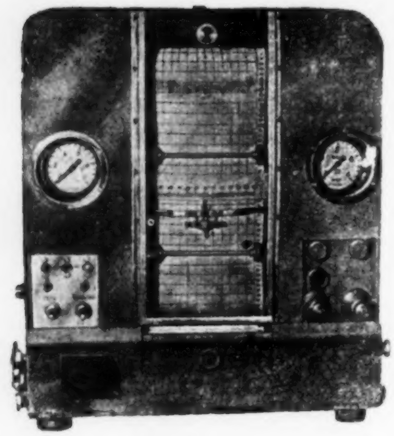

Fig. 2.

The use of the equipment in the production of expensive diamond needles reduces the amount of scrap.

The error in determining the radius of a needle does not exceed ± 0.5 μ.

In the "Measurements of time and frequency" section, equipment type UCh-2 for checking frequency and frequency-measuring instruments made by the VNIIM is exhibited. The equipment is designed for mass production checking in the range of 16 cps to 26 Mc, for checking frequency-measuring instruments with a small input power in the range of 16 cps to 250 kc and for checking frequency meters with an input power of 20 w in the range of 40-15000 cps, with a basic error of 0.1% and more.

The equipment can measure tuning forks, audio and ultrasonic oscillators, standard signal generators, frequency meters of all systems with a 20 w input power.

The frequency error of the equipment does not exceed ± 0.03%.

In the same section a pendulum astronomical clock type AChF-3 made by the VNIIFTRI and designed for astronomical observatories and time-service laboratories is also exhibited. Owing to the isochronous suspension of the pendulum, its period of oscillation is independent of possible changes in amplitude. The pendulum oscillations are sustained by short one-sided pulses produced by the clock mechanism. The combination of an isochronous pendulum with a mechanism which sustains its oscillations without infringing its isochronism, has produced a high accuracy of movement. The mean daily variation of the clock movement amounts to 0.0002-0.0003 sec.

The "Pressure measurements" section contains a VNIIK reference first-grade nonmercury piston-type barometer designed for checking stationary mercury barometers and for precise measurements of atmospheric pressures. The measuring element of the instrument consists of a piston pair without piston packing.

The measuring range is 700 to 780 mm Hg. The measurement error does not exceed ± 0.002%.

In its accuracy and stability of readings the barometer is in no way inferior to stationary mercury barometers, possessing at the same time compactness and ease of application. Its great advantage is the absense of mercury.

The "Measurements of temperature" section contains an infrared pyrometer type IKP-57 developed by the KhGIMIP (Fig. 2) for precision measurements of temperatures in the range of 400-1100°C. The instrument is based on the zero modulation method, namely the brightness of the measured object is compared with that of a standard radiator, a temperature lamp. The radiations receiver only serves as an indicator of the equality of brightness of the two radiators. This arrangement eliminates completely the difficulties connected with the instability of radiation receivers.

The pyrometer uses an infrared monochromator which separates the required narrow band in the spectrum. This provides the possibility of determining accurately the effective wavelength of the pyrometer, which is necessary for calibration operations.

The VNIIK is exhibiting a set of mercury in glass thermometers with a uniform scale designed for use as 1st-grade thermometers for calibration of standard 2nd-grade thermometers and for measuring temperatures with high precision in the range of 0 to + 100°C.

The set for the range 0 to + 60°C consists of 15 thermometers, each with a scale of 4°C graduated in 0.01°C.

The set for the range of + 60 to + 100°C consists of 5 thermometers, each with a scale of 8°C graduated in 0.02°C.

The errors do not exceed ± 0.002°C for the range of 0 to 60°C and ± 0.004°C for the range of + 60 to + 100°C.

The "Electrical and magnetic measurements" section has been supplemented by a considerable number of standard measuring instruments. The VNIIM is exhibiting the following four sets.

Equipment UBS-1 for dc measurement of high resistances between 10^9 and 10^{14} ohm at voltages of 2 to 500 v. The principle of its operation is based on measurement of the change of capacity, and the time taken for the change, when a constant voltage is held across the terminals of a discharging capacitor by means of lowering its capacity.

The errors of measurement do not exceed ± 0.5%.

Equipment for magnetic ac measurements type UMIPT-1 designed for testing toroidal ferromagnetic cores.

The equipment measures hysteresis and eddy current losses by the wattmeter method and provides images of hysteresis loops, and differential permeability curves at any point of the hysteresis loop.

The equipment provides the following characteristics: the relation of permeability or the alternating component of magnetic induction to the alternating or permanent magnetic field strength and the relation between the permanent component of magnetic induction and the permanent field strength.

It covers a range of 50 to 10000 cps.

Errors of measurement amount to ± 3 to ± 10% (depending on the region of measurement).

Equipment type UIMM-2 for measuring magnetically hard materials designed for testing samples of ferromagnetic materials operating at higher frequencies (ferrites, ferroelectric materials, thin metal sheets, etc). The equipment is based on a bridge method of measurement. Its frequency range is 20 kc to 1 Mc.

Errors in measuring equivalent loss resistances and permeability do not exceed ± 5%. The inductance measurement range extends from 100μh to 50 mh and the resistance range from 1 to 10000 ohms. The errors in measuring inductance do not exceed ± 1% and those of resistance ± 5%.

Equipment type UKIP-2 for measuring hysteresis and eddy current losses in magnetic materials by the calorimetric method is used for measuring hysteresis and eddy current losses in small samples of magnetic materials and in ferrites, dielectrics, thin metal sheets, etc.

Its frequency range is from 20 kc to 1 Mc. Power range from 0.1 to 2 w. Errors of measurement are ± 5 to ± 2% respectively.

The VNIIK is exhibiting in this section a number of instruments and equipments.

A box of large capacitors consisting of paper, plastic film and electrolytic capacitors. The range extends from 1 to 11000 μf. Owing to the use of capacitors in a strictly defined condition the stability of the capacity with time is ensured.

Boxes of large inductances consist of coils whose permalloy cores have air-gaps. Their range extends from 1 to 1000 h.

Equipment for measuring large inductances and capacities type UBIE-1 was designed first of all check the boxes of large inductances and large capacitors which are used as reference measures in checking ac bridges. The measurement of capacity and inductance can be carried out in a wide range of applied voltage (in a ratio of 1 : 50).

The operating frequencies are 50 and 100 cps. The measurement errors of capacities and inductances do not exceed ± 0.2%.

Equipment type UPPV for measuring loss angles of standard capacitors and the time constant of large non-reactive resistors is designed for investigating measuring capacitors and resistance boxes in the audio-frequency range. The equipment consists of a bridge circuit with capacitors and an auxiliary arm.

It is possible to measure by means of this equipment loss angles of capacitors from 10 μμf to 1 μf and the time constant of resistors from 500 ohm to 20 meg.

Its frequency range is 40 to 20000 cps. The error in measuring the loss angle does not exceed $2 \cdot 10^{-5}$ rad.

The errors in measuring the time constant does not exceed $2 \cdot 10^{-9}$ sec.

A three-phase portable equipment PTU-2 is used for checking active and reactive power electricity meters for single and three phase operation at 50 cps as well as ac ammeters, voltmeters, wattmeters and phase-meters grade 1.5 and lower.

The equipment is mounted in two suitcases one of which contains all the voltage and the other all the current units. The voltage ranges are 150-300-380 v. The current ranges are 0.5-1-2-5-10-20 and 50 amp. Its total weight is 80 kg.

The "Radiotechnical measurements" section has been supplemented by new products of the VNIIFTRI which include standard attenuators in the 0.75 to 4 cm band, designed for checking and calibrating industrial attenuators by the substitution method, and a double thermistor bridge type DTM-6 for measuring power when checking, adjusting and repairing UHF equipment. The top measuring limits are 15, 50 and 150 μw. Measurement errors do not exceed values in the region of $\pm$ (0.03A + 1) μw, where A is the top limit of measurement. The thermistor resistance is 50-400 ohms.

The same section includes a transit power millivoltmeter type MPM-1 developed by the KhGIMIP and designed for measuring the power transmitted down a waveguide channel. It can be used for checking and calibrating thermistor and bolometric power meters. It operates in the two-and three-centimeter range.

The power measuring range is from 15 to 80 mw with a voltage standing-wave ratio of 1.03 and from 50 to 800 mw with a voltage standing-wave ratio of 1.20.

Measurement errors do not exceed $\pm$ 6%.

The models of the precision instruments described above are the latest developments of the Committee's Scientific Institutes. The instrument-making industry must organize their production on a scale which would satisfy the requirements of the national economy.

The assimilation of these instruments by industry and scientific establishments will help to accomplish the tasks assigned by the 21st Congress and the June Plenum of the Central Committee of the CPSU to Soviet science and technology in the sphere of further technical progress.

INTERFERENCE–FRINGE COUNTER FOR MEASURING SMALL LENGTHS

V. P. Koronkevich and Yu. I. Trulev

A tendency has developed in recent years to make instruments [1, 2] which provide absolute measurements by counting interference fringes. The development of electronics provides convenient and reliable methods for implementing these ideas. Interferometers in conjunction with fringe counters considerably widen the scope of interference measurements at least with respect to their wider application.

On the basis of interferometer PIU-1 (it is also possible to take PIU-2 or PIU-3) and a standard computer PS-64 we constructed (Fig. 1) an equipment which provides measurement of small lengths up 1-2 mm.

Light rays from a monochromatic source 1 (mercury lamp of the "Étalon" plant) are projected by condenser 2 onto the collimator slit 3. A beam of parallel rays leaves the collimator through light filter 4 (the filtered wave length is $\lambda = 0.5461\ \mu$) and enters the contact interferometer PIU-1, which is essentially an interferometer of the Michelson type, placed in the forward segment of a microscope eyepiece. Diaphragm 5 of 10 × 20 mm is placed in the focal plane of the eyepiece. A quartz block gage 6 is rigidly connected to the interferometer table.

Since the interferometer branches are not equal in length, the light rays will have different path lengths which will determine the shape of the interference picture. By turning mirror 8 through small angles it is possible to obtain in the focal plane of the eyepiece interference fringes of any desired widths, and direction.

The displacement of mirror 7 by the contact tip changes the differences in the light paths. The interferometer is adjusted in such a manner that diaphragm 5 cuts out of the interference picture parts of the interference fringe. In this case the movement of mirror 7 along the optical axis will produce periodic changes in the intensity of light at the interferometer output. The variations in intensity are recorded by photomultiplier 9 type FÉU-19M, formed in the shaping device 11 into pulses of equal amplitude and shape and then fed to computer 12. Displacement of the mirror by $\lambda/2$ corresponds to one pulse at the input of computer 12.

Supplies for the circuit are provided by power pack 10.

In this interferometer the measured length is determined from the formula

$$L = N\frac{\lambda}{2}, \tag{1}$$

where L is the measured length;

N is interference ordinal (number of pulses);

λ is the light wavelength.

The shaping circuit consists of an amplifier with a direct coupling and a relaxation relay with one stable position. The gain of the amplifier is 15-20. The top limit of its range is determined by the required count rate. For measuring purposes 1000 pps is an acceptable rate; all the pulses fed to set PS-64 input will be registered on the electromechanical counter.

The photomultiplier is fed from the stabilized rectifier BS-9. The potential divider resistors were selected with an error not exceeding 1-2%. The supply voltage is 1300 v.

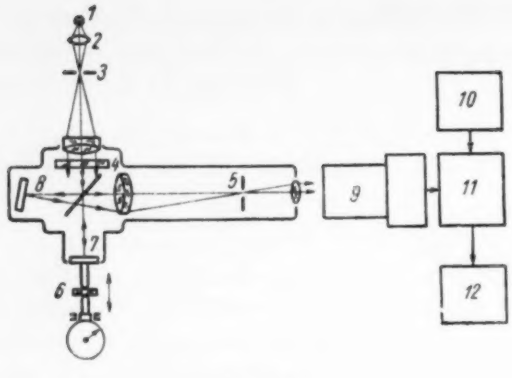

Fig. 1.

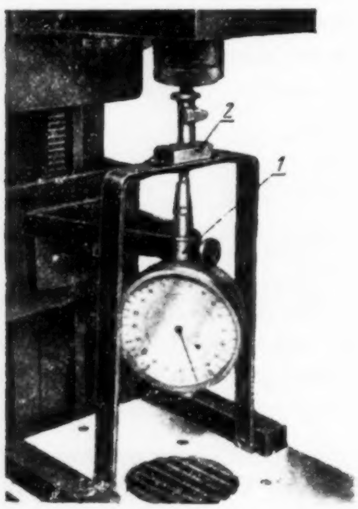

Fig. 2.

The interferometer in conjunction with the fringe counter can be easily adapted for checking micron gages of the clockwork type, screws of eyepiece micrometers and other instruments. For this purpose support 1 (Fig. 2) which carried the indicating gage under test was fixed to the bracket of interferometer PIU-1.* The quartz block gage 2 (in Fig. 1 numbered as 6) is rigidly fixed to the interferometer table. Any displacement of the table and, hence, the quartz gage by means of a micrometer screw is conveyed to the interferometer and measured instrument contact tips. The parallelism of the quartz-gage displacement is checked by means of the autocollimator. This arrangement is also convenient for checking the error in the counter readings at different rates of fringe displacement in the field of vision by substituting the micron indicating gage by more accurate instruments (spring microindicating gage). These instruments had previously been calibrated directly in light wavelengths with an error of 0.1-0.2 of a fringe).

The photoelectric system registered only integral interference ordinals. The measured lengths, however, contained a whole number of fringes and a certain fraction, thus the counter registered a shorter length than the actual one. The corresponding error lies within the limits of (− 2, 0) in the pulse count or within ($-\lambda$, 0) in units of length, since the distance between fringes in Michelson's interferometer amount to $\lambda/2$. There are no reasons to assume that the fractions of a fringe will have any preferential values in this type of measurement. Therefore the distribution of errors should be taken as uniformly distributed within the limits ($-\lambda$, 0).

Under such conditions the mathematical expectation of the error value of this method will equal (− 1) pulses or $-\lambda/2$. The mean-square deviation will be correspondingly equal to $1/\sqrt{3}$ in pulses and $\lambda/2\sqrt{3}$ in units of length, i.e., for $\lambda = 0.5461\ \mu$ the mean-square error will be equal approximately to $0.16\ \mu$.

If it is assumed that the interferometer with photoelectric recording is free from any other systematic or random errors, it should be considered, in evaluating the measurement results, that the mathematical expectation of the error value is equal to (− 1) or ($-\lambda/2$). Hence, it is better to take value (N + 1) pulses as the measurement result, i.e.,

$$L = (N+1)\frac{\lambda}{2}. \tag{2}$$

In this case the maximum possible error will be $\lambda/2$, and the mean-square deviation $\lambda/4\sqrt{3}$ (with $\lambda = 0.5461\ \mu$ this amounts approximately to $0.1\ \mu$), since if condition (2) holds, the error will be uniformly distributed in the interval ($-\lambda/2$, 0).

There is no point in calculating a limiting error based on an assumed probability with a uniform distribution.

Formulas (1) and (2) have been derived on the assumption that the rays strike the surface of plates 7 and 8 at right angles (Fig. 1). The formulas are not completely accurate since they do not take into account variations

* The position of the indicator gage under test is not the same as its normal position in use; this defect however can be easily rectified in the permanent equipment.

in the interference image due to the finite dimensions of the input diaphragm 5 opening. The effect of these dimensions will contribute to the measurement results a systematic error.

It is possible to decrease this error, which is determined from expression

$$\Delta L=(N+1)\frac{\Delta\lambda}{2}, \tag{3}$$

by decreasing the relative error in determining the wavelength, since

$$\Delta L=(N+1)\frac{\lambda}{2}\cdot\frac{\Delta\lambda}{\lambda}. \tag{4}$$

The relative error in determining the wavelength depends both on the dimensions of the slit 8 (Fig. 1) and on the error in determining the wavelength itself. The latter error is small and can be neglected.

For practical calculations it is more convenient to introduce the concept of an effective wavelength, which was shown by A. N. Zakhar'evskii [3] to equal to

$$\lambda'=\frac{2}{1+\sqrt{1-A^2}}\lambda,$$

where A is the aperture of the illuminating beam.

On the other hand

$$\lambda'=\lambda+\Delta\lambda$$

and, hence,

$$\frac{\Delta\lambda}{\lambda}=\frac{1-\sqrt{1-A^2}}{1+\sqrt{1-A^2}}. \tag{5}$$

Then the expression for the error depending on the aperture of the illuminating beam will be

$$\Delta L=L\frac{1-\sqrt{1-A^2}}{1+\sqrt{1-A^2}}. \tag{6}$$

Taking into consideration that the counter does not record fractions of the interference ordinal, but counts only integral fringes, we obtain the final expression for the error in determining the length: *

$$\Delta L\leqslant\left[(N+1)\frac{\lambda}{2}-L_0\right]+L\frac{1-\sqrt{1-A^2}}{1+\sqrt{1-A^2}}+\frac{\lambda}{2}. \tag{7}$$

In our installation the value of the aperture did not exceed 0.0008, hence the value of the error determined by the second term of (7) can be neglected. The basic error indetermining the length will, therefore, depend on the third term of (7).

For an experimental confirmation of these conclusions 10 different length values were measured. Each value set on a spring microindicating gage was determined 33 times. The value of the set length was determined in advance by absolute measurements.

The mean-square error of the length measurement results on the interferometer with the counter was, for all the lengths measured, within the limits of 0.15 to 0.25 μ.

It was previously shown that the theoretical expectation of the mean-square error should have the value of 0.16 μ. Above discrepancy is due to the error introduced by an inaccurate setting of the spring-gage pointer to

* In deriving this formula we used E. F. Dolinskii's data.

its scale. The value of this error was determined experimentally and its value did not exceed 0.1 μ.

The use of (2) does not lead to a decrease in the error, although the mean value of σ becomes a little smaller. The latter is also explained by the fact that the measuring results are distorted by the inaccurate setting of the spring microgage pointer.

In order to record the fractions of a fringe, a bistable trigger was included in the photoelectric circuit. The transition from one stable condition into the other was caused by the extreme values of the photoelectric current which were recorded by a neon tube. This arrangement provided a recording of the interference picture at the beginning and the end of the count with an error not exceeding 0.5 of a fringe.

When it is possible to record half pulses the error does not exceed one pulse. The mean-square error was thus reduced to 0.13 μ.

Tests of the micron indicator gage on the interferometer and a universal microscope coincided within the error of the universal microscope.

SUMMARY

1. For measuring small lengths (1-2 mm) it was found expedient to construct an interferometer with a fringe counter by using standard instruments produced by our industry.

2. The mean-square error of such an interferometer does not exceed 0.22 μ, which is perfectly satisfactory for the majority of measurements in the engineering industry.

3. The interferometer can be easily adapted for measuring micron indicator gages, screws of eyepiece micrometers, for determining coefficients of linear expansion and similar operations.

4. For more accurate measurements, the error of the set can be reduced by means of a device which registers fractions of the interference ordinal with an error of 1/2 a fringe.

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MICROSCOPE FOR MEASURING INTERNAL THREADS

A. I. Omel'chenko

Existing indicating and micrometer instruments for measuring internal thread elements have considerable measuring errors; the horizontal telescope caliper and the imprint method are more precise, but they are very slow in operation, which is their great defect.

The microscope for measuring internal threads, described below, provides better measurements of the three basic internal thread elements with a nominal diameter of 18 mm and over. The instrument is based on the double microscope of Academician V. P. Linnik.

The double microscope consists of two tubes whose axes are perpendicular to each other. The image of a flat slit is projected by means of one of the tubes onto the surface under test at an angle of 45° to the surface and is observed by means of the other tube at an angle of 45° to the surface of the detail. As the result of the roughness of the surface the observer will see (in the general case) image of the slit distorted according to the profile of the surface instead of a straight one.

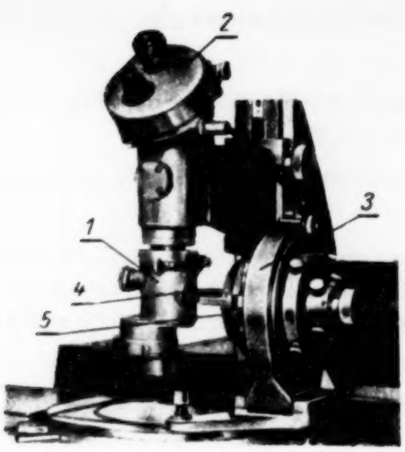


Fig. 1.

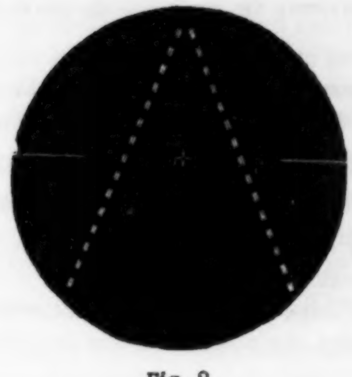


Fig. 2.

Fig. 3.

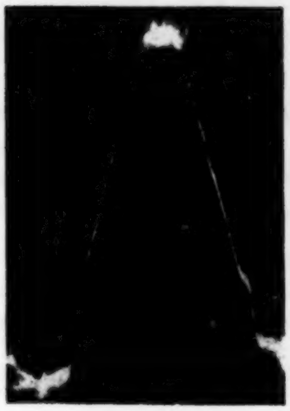


Fig. 4.

For an efficient use of the double microscope in measuring internal thread with a pitch exceeding 0.5 mm, the flat slit is replaced by a deep slit of the same shape as the profile of the thread. This arrangement provides a clear image of the side surfaces section of the thread along its entire profile from the head to the root of the thread.

The thread-measuring microscope IZK-59 is used as an attachment to the universal measuring microscopes UIM-21 and UIM-22 and consists of the measuring head 1 (Fig. 1), eyepiece head 2 and a centering chuck 3. Extension 4, some 65 mm long, has a prismatic head, is placed inside the tested geared ring 5 during measurements and operates on the principle of a double microscope.

The measuring head contains the basic optical elements of the device and the slit. The same deep slit of the microscope can serve for measuring metric and inch threads with a profile angle of 55°. The illumination of the slit is accomplished by the lighting system of microscopes UIM-21 or UIM-22.

Measuring head 1 is screwed into the opening which serves to fix the objectives to the main microscope body. The eyepiece head contains a circular dial with graduations of ± 4° and a scale (Fig. 2) and serves to measure the angle of the profile image seen in the eyepice. The eyepiece head is fixed to the upper part of the main microscope. Centering chuck 3 serves to hold and center the measured geared article with respect to the axis of rotation of the centering chuck. The centering chuck is fixed to the grooves of microscope UIM-21 or the stage of microscope UIM-22.

A thin bright outline of the thread profile (Fig. 3) appears on a black background in the eyepiece field of vision together with a bright image of the eyepiece scale (Fig. 2).

It is possible to measure by means of microscope IZK-59 threads with a pitch from 0.25 to 2 mm and a mean diameter of 18 to 98 mm. The upper limit of diameter measurements can be increased to almost double the size of the UIM-21 microscope transverse scale, i.e., up to 190 mm by moving the centering chuck with respect to the stage of microscope away from the observer.

For measuring the pitch and the mean diameter the calibrations of microscopes UIM-21 and UIM-22 are used.

The error of measurement in the UIM-21 microscope amounts to ± 0.002 mm for the pitch; ± 0.003 mm for the mean diameter and for half the profile angle, 8 to 15' depending on the pitch.

Thus, the microscope for testing internal threads provides measurements of the three main elements of the thread and, what is especially important, it is a noncontact device.

Another valuable property of the thread-measuring microscope consists in the possibility of observing, with a slight defocusing, the thread profile with its head and root and thus evaluating both the quality of the surface finish and the shape of the head and root of the thread. The image seen in the eyepiece can be easily photographed by using, the eyepiece as the photoobjective.

The principle of the thread-measuring microscope design was proved to be efficient for a wide application in the field of measurements owing to the deep slit, which provides clear images of very deep profiles, and to its special prismatic head, which brings the double microscope into a relatively small opening (18 mm) and provides practically all the measuring facilities of a normal double microscope for measuring outside surfaces of details.

To date it was almost impossible to obtain an idea of a tooth profile-shape in a small module worm-gear wheel, but now this has become possible owing to the thread-measuring microscope. In order to examine a worm-gear tooth profile and determine the quality of its finish 2 to 3 minutes are required, and for obtaining a photograph of the profile, 15 to 20 min (Fig. 4). Figure 4 clearly shows traces of wear in the tooth.

Above method can be applied in heavy engineering and shipbuilding for measuring elements of nut threads of a large pitch of the order of 5-20 mm and in general in cases when it is required to measure the shape of grooves on internal surfaces of various details.

At present the IZK-50 type microscope is serially produced by one Leningrad Council of National Economy plant.

A KINEMATIC METHOD OF MAKING DETAILS WITH CURVILINEAR CROSS SECTIONS AND A TECHNIQUE OF EVALUATING ITS ACCURACY

N. M. Karelin

In instrument-making many details with curvilinear cross sections are used, such as cams, templets, gasmeter vanes, outside surfaces of noncircular wheels, polyhedrons, etc.

At present there are two methods of making these details; the duplicating and the kinematic (nonduplicating) methods.

In the duplicating method the cutting tool reproduces the movement of the feeler with respect to the sample (model).

In the kinematic method the blank and the tool are interconnected by a kinematic device which provides a relative movement of the tool with respect to the blank in such a manner as to form the required profile.

In the present work the author aims at developing a method of constructing kinematic devices for nonduplicating machining of cylindrical details with curvilinear cross sections. This method should provide the required profile within the limits of permissible deviations of its shape. Developing kinematic schemes on this basis leads to a problem of the theory of function approximations.

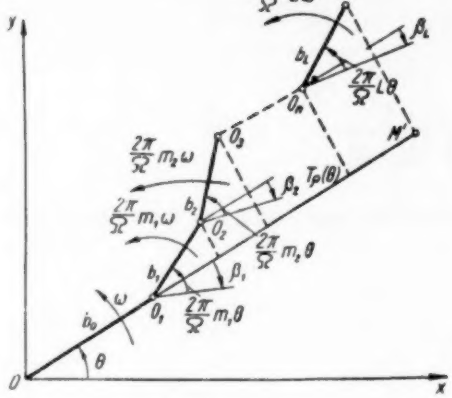


Fig. 1.

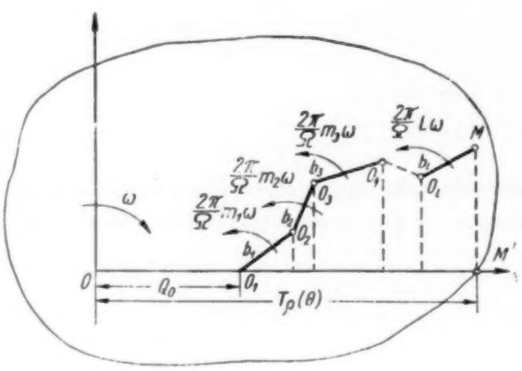


Fig. 2.

It is known that such problems can be solved in one of two ways, depending on whether the approximations are made by means of normal or trigonometrical polynomials [1]. In the solution of this problem we shall use trigonometrical polynomials.

Let the curve which represents the contour of the detail or its equidistantial line be given in the polar system of coordinates by function $\rho = f(\Theta)$.* We shall extend function $f(\Theta)$ periodically with the period Ω.

Let us take as an approximating curve the curve described by the projection of the end of a broken line (Fig. 1) onto the extension of its first segment b_0, and let the broken line consist of constant length segments, which rotate at different velocities, multiples of the angular velocity of b_0. The equation of a curve of an approximating class in polar coordinates will take the form

$$T_\rho(\Theta) = b_0 + \sum_{\kappa=1}^{L} b_\kappa \cos\left(\frac{2\pi}{\Omega} m_\kappa \Theta - \beta_\kappa\right), \quad (1)$$

where $L + 1$ is the number of moving links;

b_k is the length of a link;

β_k is the angle of the initial phase;

$\Theta = \omega t$;

ω is the absolute angular velocity of link b_0,

$\underline{t}$ is time;

$(2\pi/\Omega) \cdot m_k\omega$ is the relative angular velocity of link b_0.

In order to obtain from the approximating class a curve which is nearest to the given function, let us formulate the problem in the following manner.

We have a certain plane periodic curve with period Ω, and represented in polar coordinates by equation $\rho = f(\Theta)$. The curve can be determined by its equation or by a table of the values of ρ_l, and Θ_l, with Θ_l being uniformly distributed over period Ω. It is required to determine $3L + 1$ parameters of the approximating class curves $b_0 \ldots b_L$, $\beta_1 \ldots \beta_L$, $m_1 \ldots m_L$ with a given order of polynomial L.

In solving this problem let us change the order of polynomial L until the divergence between the approximating and exact curves in the required direction lies within the limits of the permissible error $\Delta(\Theta)$, established for the deviation of the detail contour.

$$\Delta(\Theta) = |T_\rho(\Theta) - f(\Theta)|. \quad (2)$$

In order to determine the parameters of the approximating-class curves, let us represent Eq. (1) in the form

$$T_\rho(\Theta) = A_0 + \sum_{\kappa=1}^{L}\left(A_\kappa \cos\frac{2\pi}{\Omega} m_\kappa \Theta + B_\kappa \sin\frac{2\pi}{\Omega} m_\kappa \Theta\right). \quad (3)$$

*When machining is done by means of round tools (milling cutter, gear-wheel cutter, etc) $f(\Theta)$ should be represented by an equation of the equidistantial line of detail contour. When the machining is done by means of flat tools (turning, chiselling or planing cutters, etc) $f(\Theta)$ should be represented by an equation of the detail contour.

where

$$A_\kappa = b_\kappa \cos \beta_\kappa, \quad B_\kappa = b_\kappa \sin \beta_\kappa.$$

And, vice versa,

$$b_\kappa = \sqrt{A_\kappa^2 + B_\kappa^2}; \qquad \cos \beta_\kappa = \frac{A_\kappa}{\sqrt{A_\kappa^2 + B_\kappa^2}} \tag{4}$$

With $m_k = k$ for $k = 1, 2, \ldots$ we obtain a polynomial with Fourier coefficients which are determined from the following equations:

$$A_0 = \frac{1}{\Omega} \int_0^\Omega f(\Theta)\, d\Theta;$$

$$A_\kappa = \frac{2}{\Omega} \int_0^\Omega f(\Theta) \cos \frac{2\pi}{\Omega} \kappa\Theta \, d\Theta; \tag{5}$$

$$B_\kappa = \frac{2}{\Omega} \int_0^\Omega f(\Theta) \sin \frac{2\pi}{\Omega} \kappa\Theta \, d\Theta.$$

If function $\rho = f(\Theta)$ is given by a table of its values, at points $\Theta_l = l\Omega/2p$ the value of the function is $\rho_l = f(\Theta_l)$ for $l = 0, 1, \ldots 2p$, and the Fourier coefficient can be expressed according to the approximate formula as

$$A_0 = \frac{1}{2p} \sum_{l=0}^{2p-1} \rho_l.$$

$$A_\kappa = \frac{1}{p} \sum_{l=0}^{2p-1} \rho_l \cos \frac{l\kappa\pi}{p}; \tag{6}$$

$$B_\kappa = \frac{1}{p} \sum_{l=0}^{2p-1} \rho_l \sin \frac{l\kappa\pi}{p}.$$

Sometimes the selection of the approximating polynomial $T_\rho(\Theta)$ with parameters $m_k = k$ (= 1, 2,...) provide unsatisfactory results, since in order to obtain a good approximation of function $f(\Theta)$ it is necessary to take a polynomial with too many terms.

In this case it is possible to fix arbitrarily the value of m_k and, by varying the value of one of the parameters which are not being calculated, to obtain a number of solutions, selecting the one which satisfies the required conditions. Moreover for determining parameters A_k and B_k it is necessary to solve a system of $2L + 1$ equations by means, for instance, of the interpolation method, having equated to zero the difference between the given and the approximating functions for certain $2L + 1$ values of parameters $\Theta_0 \ldots \Theta_{2L}$

$$f(\Theta_0) - A_0 = 0;$$

$$f(\Theta_1) - \sum_{\kappa=0}^{L} \left(A_\kappa \cos \frac{2\pi}{\Omega} m_\kappa \Theta_1 + B_\kappa \sin \frac{2\pi}{\Omega} m_\kappa \Theta_1 \right) = 0;$$

$$f(\Theta_{2L}) - \sum_{\kappa=0}^{L} \left(A_\kappa \cos \frac{2\pi}{\Omega} m_\kappa \Theta_{2L} + B_\kappa \sin \frac{2\pi}{\Omega} m_\kappa \Theta_{2L} \right) = 0.$$

we determine parameters $A_0 \ldots A_L$, $B_1 \ldots B_L$ and by using (4) we find $b_0 \ldots b_L$ and $\beta_1 \ldots \beta_L$. Thus, the parameters of a given class of approximating curves can be determined by two methods, namely, by developing a polynomial with Fourier coefficients or by determining $2L + 1$ parameters of the trigonometrical polynomial A_k and B_k with

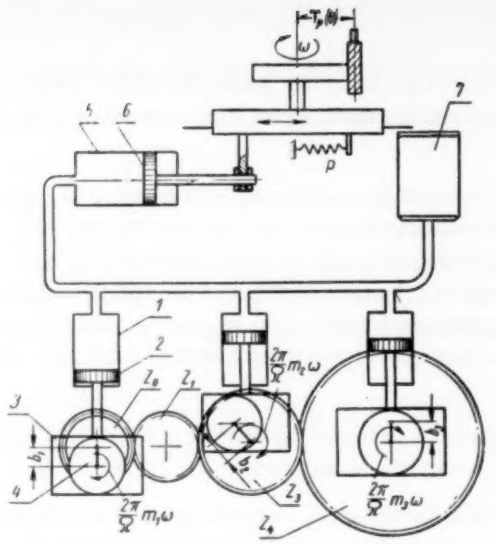


Fig. 3.

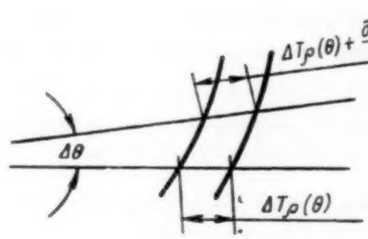


Fig. 4.

a fixed value of m_k ($k = 1, 2, \ldots$) by means of approximating to the given function $f(\Theta)$. In the second method of determining the parameters of the approximating curve it is possible to choose a polynomial of a much lower order than with the first method. This circumstance is of great practical importance, since it provides the required curve with a minimum number of links in the initial system.

Example. Let us examine an approximation by means of an approximating-class curve of the detail profile represented by equation $\rho = \Theta^2$ (an edge cam whose follower moves with constant acceleration) for $0 \leq \Theta \leq \pi/2$. Let us determine the coefficients of A_k and B_k of polynomial (3) in two cases, when $L = 1$ and $L = 2$. By using the second method of finding coefficients let us select $m_1 = 1/4$, $m_2 = 1/2$. Let us approximate by the quadratic method, i.e., let us find the minimum integral of the squared difference of the given function and the trigonometrical polynomial

$$J+\int_0^{\frac{\pi}{2}}\left[\Theta^2-\sum_{\kappa=0}^{L}\left(A_\kappa\cos\frac{2\pi}{\Omega}m_\kappa\Theta+B_\kappa\sin\frac{2\pi}{\Omega}m_\kappa\Theta\right)\right]^2 d\Theta.$$

(Let us note that $\Omega = \pi/2$ and $2\pi/\Omega = 4$).

In equating to zero the derivative with respect to parameters of A_k and B_k of integral J we obtain a system of equations in which j is at its minimum:

$$\frac{\partial J}{\partial A_\kappa}=0;$$
$$\frac{\partial J}{\partial B_\kappa}=0.$$

By solving this system and using (4) we obtain

$L=1$ $b_0=2.7957$; $b_1=2.7166$; $\beta_1=-7°45'$;
$L=2$ $b_0=3.17239$; $b_1=3.49458$; $b_2=0.3535$; $\beta_1=-6°40'$;
$\beta_2=31°50'$.

In order to evaluate the accuracy of the approximation by means of Eq. (2) let us find the distance along the radius vector between the given and the approximating curves $\Delta(\Theta)$.

The following values of $\Delta(\Theta)$ were obtained by calculation:

Θ	$f(\Theta)=\Theta^2$	$\Delta(\Theta)$ at $L=1$	$\Delta\Theta$ at $L=2$
0	0	0.0776	0.0026
$\frac{\pi}{4}$	0.6168	0.0128	0.0040
$\frac{\pi}{2}$	2.4674	0.0434	0.0022

Thus, in the above example a device with $L = 1$ will approximate with an error of 3% of f_{max} and with $L = 2$ the error decreases to 0.6%.

The representation of the trigonometrical polynomial as a curve made by the projection of the broken line which consists of rotating links onto the extension of the first link, provides approximate curves by means of a simple kinematic scheme.

In order to develop a kinematic scheme based on a chosen class of approximating curves and satisfying the practical conditions of machine tool operation, let us use the transformation of the scheme (Fig. 1), i.e., let us give radius-vector ρ a velocity $-\omega$ (Fig. 2); then the radius-vector ρ will remain stationary and the blank will rotate with respect to axis 0 with a velocity $-\omega$. By making the cutting edge of the tool coincide with point M (the tip of a flat cutter, center of a milling cutter, etc) and imparting an angular velocity $-\omega$ to the blank we shall obtain the required contour of the detail if the distance between the centers of the tool and the blank varies according to $T_\rho(\Theta)$.

For the practical implementation of the variations of the distance between the centers it is possible to construct mechanisms which would provide the addition of a finite number of harmonics.

It is possible to construct such mechanisms by interconnecting, for instance, summating mechanisms with two degrees of freedom, which add in pairs the harmonic motions produced by cosine (sine) mechanisms (for instance a cosine link mechanism, a crank-connecting rod mechanism with equal dimensions of the crank and the connecting rod, etc).

Summating mechanisms with two degrees of freedom include: bevel-gear differentials with cylindrical wheels, worm-gear transmissions, skew-bevel wheels with longitudinal displacement, as well as bar mechanisms, etc.

It is also possible to use a hydraulic mechanism for varying the distance between the centers of blank and the tool.

Figure 3 shows a schematic diagram of such a mechanism for a vertical milling machine.

Cylinders 1 whose axes are parallel have pistons 2, which are actuated by eccentric mechanisms 3, in such a manner that with an even rotation of the eccentrics 4 at velocities of $(2\pi/\Omega)\, m_1\omega \ldots (2\pi/\Omega)\, m_s\omega$, the pistons oscillate harmonically. Above angular velocities are attained by means of gears z_1 and z_2. Cylinders 1 are interconnected and also connected to cylinder 5 which has piston 6 connected to the longitudinal table of the milling machine. The hydraulic system is filled with oil from container 7. Spring P is used for establishing initial pressure. When all the pistons 2 operate simultaneously the displacement of piston 6 will be proportional to the sum of all the piston 2 displacements which vary according to the cosine law. By adjusting the lengths of cranks $b_1 \ldots b_s$ it is possible to obtain various approximating curves which represent the theoretical contours of the details.

These nonduplicating mechanisms, which provide the required variations of the distance between the centers by means of setting the lengths and initial phases of the cranks, are universally applicable and can be produced as units for attachment to machines which make details with curvilinear cross sections.

Let us now work out a general procedure for evaluating the effect of manufacturing error of mechanisms on the accuracy of the curvilinear cross sections of the details being produced. The effect of various other factors peculiar to this nonduplicating method of production (hardness, temperature and other physical and geometrical parameters which affect the accuracy of the machine, tools and attachments) we shall assume to be similar to those in normal working.

In order to obtain an equation for the errors in mechanisms based on the approximating class of curves, let us differentiate Eq. (1) and then, if we replace the differentials by finite increments, we shall have

$$\Delta T_\rho(\Theta) = \Delta b_0 + \sum_{\kappa=1}^{L} \Delta b_\kappa \cos(i_\kappa \Theta - \beta_\kappa) + \sum_{\kappa=1}^{L} [b_\kappa(\Delta\beta_\kappa - i_\kappa \Delta\Theta - \Theta\Delta i_\kappa) \sin(i_\kappa \Theta - \beta_\kappa)]. \tag{8}$$

where $\Delta T_\rho(\Theta)$ is the error in the radius-vector which determines a given profile,

$\Delta\Theta$ is the error in the position of the radius-vector,

$\Delta\beta_k$ is the error of the initial phase angle,

$\Theta\Delta i_k$ is the error in the rotation of link b_k when link b_0 rotates accurately, and

$$i_\kappa = \frac{2\pi}{\Omega} m_\kappa .$$

Let us note that since the same scheme (Fig. 2) can have several constructional forms, the errors which determine the accuracy of the mechanism do not correspond to errors Δb_k, $\Delta\beta_k$, $\Delta\Theta$ and $\Theta\Delta i_k$. The latter can be represented in form of linear functions of the error which we shall denote by Δq_r:

$$\begin{aligned} \Delta b_\kappa &= \sum_{r=1}^{N} A_{r\kappa}\Delta q_r; \\ \Delta\beta_\kappa &= \sum_{r=1}^{N} B_{r\kappa}\Delta q_r; \\ \Theta\Delta i_\kappa &= \sum_{r=1}^{N} C_{r\kappa}\Delta q_r. \end{aligned} \tag{9}$$

All the primary errors Δq_r are not necessarily included in each of the expressions (9). It is always possible to consider that Δq_r and Δq_p for $r \neq p$ are independent of each other. If the real values of the errors q_r are unknown, and only their probability characteristics are given (mathematical expectations, variances, distribution laws), it is possible to determine the corresponding probability characteristics for the required errors.

When determining the error of the profile it is possible to neglect the position error of the radius-vector, thus committing an error of the second order of magnitude. This can be seen directly from Fig. 4. Thus, it becomes sufficient to find $T_\rho(\Theta)$.

$$\Delta T_\rho(\Theta) = \Delta b_0 - \Delta\Theta \sum_{\kappa=1}^{L} i_\kappa b_\kappa \sin(i_\kappa\Theta - \beta_\kappa) + \sum_{\kappa=1}^{L}\sum_{r=1}^{N} F_{r\kappa}\Delta q_r, \tag{10}$$

where

$$F_{r\kappa} = \sum_{\kappa=1}^{L} [A_{r\kappa}\cos(i_\kappa\Theta - \beta_\kappa) + b_\kappa(B_{r\kappa} - C_{r\kappa})\sin(i_\kappa\Theta - \beta_\kappa).$$

Hence,

$$M\Delta T_\rho(\Theta) = M\Delta b_0 - M\Delta\Theta \sum_{\kappa=1}^{L} i_\kappa b_\kappa \sin(i_\kappa\Theta - \beta_\kappa) + \sum_{\kappa=1}^{L}\sum_{r=1}^{N} F_{r\kappa} M\Delta q_r; \tag{11}$$

$$D\Delta T_\rho(\Theta) = D\Delta b_0 + D\Delta\Theta\left[\sum_{\kappa=1}^{L} i_\kappa b_\kappa \sin(i_\kappa\Theta - \beta_\kappa)\right]^2 + \sum_{\kappa=1}^{L}\left(\sum_{r=1}^{N} F_{r\kappa}\right)^2 D\Delta q_r. \tag{12}$$

where M and D together with the notation of the error denote, respectively, the mathematical expectation and dispersion of the error.

In the case of a normal-distribution law it should be considered that the tolerance which limits each error is equal to

$$\begin{aligned} q_r \max &= 3\sigma_r; \\ \Delta b_c \max &= 3\sigma_b; \\ \Delta\Theta \max &= 3\sigma_\Theta, \end{aligned}$$

and the limiting value of $\Delta T_\rho(\Theta)$ can be determined from the formula

$$\Delta T_\rho(\Theta)\max = 3\sqrt{D\Delta T_\rho(\Theta)} + M\Delta T_\rho(\Theta) = M\Delta b_0 + M\Delta\Theta\sum_{\kappa=1}^{L} i_\kappa b_\kappa \sin(i_\kappa\Theta - \beta_\kappa) + \sum_{\kappa=1}^{L}\sum_{r=1}^{N} F_{r\kappa} M\Delta q_r +$$

$$+\sqrt{\Delta b_{0\max} + \Delta\Theta_{\max}\left[\sum_{\kappa=1}^{L} i_\kappa b_\kappa \sin(i_\kappa\Theta - \beta_\kappa)\right]^2 + \sum_{r=1}^{N}\left(\sum_{\kappa=1}^{L} F_{r\kappa}\right)^2 \Delta q_r \max} \tag{13}$$

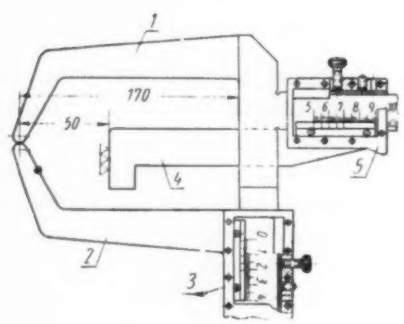
Thus, by using (13) with normalized errors $\Delta b_0 \max$, $\Delta\Theta_{\max}$ and $\Delta q_{r\max}$ it is possible to determine the limiting value of $\Delta T_\rho(\Theta)$.

LITERATURE CITED

[1] V. L. Goncharov, The Theory of Interpolating and Approximating Functions [In Russian] (GITTL, 1954).

WALL GAGE

S. N. Lutmanova



For determining the thickness of a wall over a given length a special slide gage (see figure) whose construction is similar to that of a tooth gage is used at our factory. The wall gage consists of a square with scales marked on its sides. Feeler 1 is rigidly fixed to the square, feeler 2 is fixed to frame 3 which has a vernier scale. Stop plate 4 is fixed to frame 5 which also has a vernier scale and moves perpendicularly to the first scale.

MECHANICAL MEASUREMENTS

A MANOMETER WITH AN EFFECTIVE PISTON AREA UNCHANGED BY PRESSURE

M. K. Zhokhovskii

The development of a manometer whose piston area remains constant at high measured pressures is of unquestionable practical interest. The possibility of solving this problem was analyzed in [1] on the basis of correction formulas. It appears that by selecting suitable materials and dimensions of the cylinder and piston it is possible in practice to ensure a constant area only in differential pistons; for other piston systems such a solution is difficult or impossible.

In this work a more general solution of the problem is attempted. Let us examine what are the prospects in this respect provided by the theory of an unpacked piston.

It follows from [2, 3] that the variations of the effective area of the piston with pressure can be represented in a general case in the following manner

$$\Delta S = S_0 \lambda p, \tag{1}$$

where S_0 is the initial value of the effective area of the piston at atmospheric (in practice, a bit larger) pressure;

p is the pressure measured by the manometer;

λ is the generalized coefficient of the piston area variations.

Quantity λ depends on the dimensions of the piston and the cylinder and on their elastic constants. For each type of a piston system this relation differs.

Let us take a system with a simple piston and normal cylinder. In this case the expression for λ takes the form of

$$\lambda = \frac{3\mu_1 - 1}{E_1} + \frac{1}{b}\left(\frac{k}{2} - k_1\right), \tag{2}$$

where

$$k = \frac{a}{E}\left[\frac{R^2 + a^2}{R^2 - a^2} + \mu\right] + \frac{b}{E_1}(1 - \mu_1) \tag{3}$$

and

$$k_1 = \frac{b}{E_1}\mu_1. \tag{4}$$

Here a is the internal radius of the cylinder;

R is the external radius of the cylinder;

b is the radius of the piston;

E and E_1 is the moduli of elasticity of the cylinder and the piston;

μ and μ_1 is the Poisson coefficients of the cylinder and the piston.

By subsituting in (1) the value of λ from (2) we obtain

$$\Delta S = S_0 p\left[\frac{3\mu_1-1}{E_1}+\frac{1}{b}\left(\frac{k}{2}-k_1\right)\right]. \tag{5}$$

It follows from [2 and 3] that expression (5) for the variation of the effective piston area with pressure consists of three components:

$$\Delta S = \Delta S_1 + \Delta S_2 + \Delta S_3. \tag{6}$$

Variations of the piston-face area

$$\Delta S_1 = -2S_0 \frac{p}{E_1}(1-2\mu_1). \tag{7}$$

Variations of the area caused by inclination of the piston side surface produced by uneven strain due to variable pressure in the gap

$$\Delta S_2 = \frac{S_0 p}{E_1}(1-\mu_1). \tag{8}$$

Variations of the effective area of the piston due to changes in the liquid friction force in the deformed gap

$$\Delta S_3 = \frac{S_0 p}{b}\left(\frac{k}{2}-k_1\right). \tag{9}$$

From comparison of (7)-(9) with (5) the following conclusion can be immediately drawn. The first term of (5) represents the variations of the area due to the total strain of the piston under the effect of the constant measured pressure at the face and the varying pressure in the gap against the side surface, that is it represents (7) and (8). Correspondingly the second term $S_0p/b\,(k/2-k_1)$ accounts for the variations of the effective piston area due to changes of the friction force in the unevenly deformed gap, that is Eq. (9), and coefficients k and k_1 together characterize the radial strain of the cylinder and piston.

It will be seen that the first term of (5) $S_0p(3\mu_1-1\,/E_1)$ is determined by the elastic constants of the cylinder alone. Even with normal steel, values of μ_1 (0.25-0.28) make the first term only a small fraction of the second. With $\mu_1 = 0.33$ the first term becomes practically equal to zero. Values of μ_1 approaching 0.33 are found in very hard alloys, which in general are most suitable for pistons used at very high pressures. Hence, the effect of the first term of the effective piston area increment can be neglected in practice and it will not cause any theoretical difficulties.

Let us now examine the second term of (5). As it has already been noted it is due to changes in liquid friction force which is in turn determined by strains in the piston and cylinder. The calculation of strains in piston systems is based on (see [3]) Lamé's well-known equation for thick-walled pipes, which has the form

$$u=\frac{1-\mu}{E}\cdot\frac{a^2p_c-R^2p_e}{R^2-a^2}\varrho+\frac{1+\mu}{E}\,\frac{a^2R^2(p_c-p_e)}{(R^2-a^2)\,\varrho}+\frac{p_e\mu}{E}\varrho.(10) \tag{10}$$

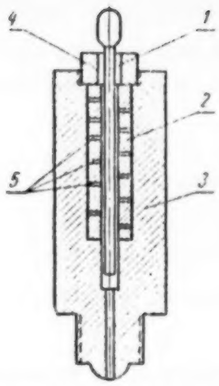
where u is the displacement of the point under consideration;

ρ is the current radius;

p_i is the internal pressure;

p_e is the external pressure (the remaining notations are the same as before).

In (10) the last term corresponds to the increment of the radius due to axial compression of the cylinder by pressure at its face.



Inspection of (10) shows that displacement in a solid cylinder due to external pressure and in a hollow one loaded from inside and outside by equal pressure are the same both in value and direction. In fact for a solid cylinder ($a = 0$) and for a hollow one with $p_i = p_e$ the second term in (10) is reduced to zero and the first one becomes $-(1-\mu)(p_e\rho)/E$.

With reference to the piston system of the manometer in question this result leads to the following conclusion. The displacements of the two practically equal radii, that of the piston and that of the internal cylinder, will be the same if the cylinder is symmetrically loaded on the side of the gap and externally by the same pressures. In this case the gap and the force of fluid friction will remain constant, and thus the second term of (5) will become zero.

A piston system in which above conditions are fulfilled is represented schematically in the figure attached. Piston 1 is carefully fitted to the cylindrical insert 2, whose external surface is in turn fitted into the channel of cylinder 3. Insert 2 is held in cylinder 3 by thrust nut 4. The pressure in the gaps between the piston and the insert and between the external surface of the insert and the main body is equalized by means of radial holes 5 extending along the whole length of the insert. Owing to the constant flow of the liquid the distribution of pressure along each section will be equalized with a stabilized movement and thus the required conditions for a constant gap between the piston and the cylindrical insert will be fulfilled.

The suggested solution of the problem with respect to a simple piston in a normal cylinder is valid for any other piston system. To what extent it will be possible to implement it in practice will be shown by the results of the tests which are being carried out.

SUMMARY

Conditions under which the effective area of an unpacked piston of a manometer is independent of pressure were analyzed. An arrangement of a piston system with a piston area unchanged by pressure is suggested.

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RESISTANCE TO SHOCK OF AN AUTOCOMPENSATED MANOMETER

V. I. Bakhtin

Vacuum manometers usually work under conditions of vibration and shocks. In vacuum gages with elastic elements the effects of vibrations and the measured pressure are of the same nature but differ in their rate of variations. This difference can be used in an autocompensated manometer [1, 2, 3] for suppressing the interference.

Let us assume on the basis of electronic tube manufacturing data that the energy of the vibrations is 5 $erg \cdot cm^{-2}\,sec^{-1}$ and the period of the fundamental 0.05 sec.

When the feedback circuit is disconnected in an autocompensation manometer, it operates as a normal strain manometer.

The equation of the movement of a bellows pressure-gage envelope can be written as

$$m\Delta\ddot{W}_0+2\eta\Delta\dot{W}_0+K_{en}\Delta W_0=F_0\sin(\omega t+\nu).$$

Here m, 2η, K_{en} are respectively the vibrating mass, damping and stiffness of the envelope.

ΔW_0 is its displacement from the balance position;

F_0, ω, ν is the amplitude, frequency and phase of the effort;

t is the time.

If K_{en} = 10^6 dyne/cm, m = 50 g, and 2η = 350 g/sec, the period of natural oscillations of the envelope will be

$$T=2\pi\sqrt{\frac{m}{K_{en}}}\simeq 0.45\ \text{sec}.$$

i.e., it resonates with the fundamental frequency of the mechanical interference spectrum. The energy of oscillations $E = 2m\,[\pi\Delta W_{0\,amp}/T]$ is in the main dissipated in a nonconvertible manner on overcoming active resistance. The energy dissipated during one period of oscillations is

$$\Delta E_T=E_1\left(1-\frac{E_2}{E_1}\right)=E\left[1-\left(\frac{\Delta W_{02}}{\Delta W_{01}}\right)^2\right]=2m\left[\frac{\pi\Delta W_0\text{amp}}{T}\right]^2\left[1-l^{-\frac{2\eta}{m}T}\right],$$

and, hence, per second

$$\Delta E_{sec}=\frac{\Delta E_T}{T}.$$

In order to make the envelope oscillations continuous it is necessary to supplement the dissipated oscillatory energy from an external supply, which with an instrument base area S = 65 cm^2 will be

$$\Delta E_{sec}=5\cdot 65=325\ \text{erg}.$$

On the assumption that the instrument frame is perfectly rigid, no damping devices are used and all the energy supplied externally is employed to sustain the envelope oscillations, whose required amplitude is determined from

$$\Delta W_{0\ \text{amp}}=\frac{T}{\pi}\sqrt{\frac{T\Delta E_{sec}}{2m\left[1-l^{-\frac{2\eta}{m}T}\right]}}=0.1\ \text{mm}.$$

This example shows that, with the assumed parameters, a bellows pressure gage without feedback cannot be used for measuring gas pressures below $3\cdot10^{-1}$ mm Hg.

When the autocompensation circuits are connected it is necessary to consider oscillations of a closed autocompensation system as a whole, i.e., to solve an equation of the form:

$$m\Delta\ddot{W}_0+2\eta\Delta\dot{W}_0+K_{en}\Delta W_0=F_0\sin\omega t-P, \tag{1}$$

where P is the compensating force. For a magnetoelectric compensating mechanism whose winding has a resistance R and inductance L the following expression holds:

$$\dot{P}+\frac{R}{L}P=\frac{K_{mc}}{L}U_{ce} \tag{2}$$

Here K_{mc} is the conversion factor between the compensating force and the current I flowing in the winding;

U_{ce} is the control element output voltage fed to the winding terminals.

For an electronic indicator of small displacements with a control organ comprising a power amplifier with a gain correction by means of the first derivative of the indicator signal U_{ind} it is possible in turn to write

$$U_{ind} = K_{ind}\Delta W_0; \tag{3}$$

$$U_{ce} = K_{o.y} U_{ind} + \varkappa \dot{U}_{ind}, \tag{4}$$

where K_{ind}, $K_{ce.y}$ and $\varkappa$ = const are transfer constants of various elements.

By substituting in (2) expressions (3) and (4) we obtain

$$\dot{P} + \frac{R}{L} P = \frac{K_{ind} K_{ce} K_{mc}}{L} \Delta W_0 + \frac{K_{ind} \varkappa K_{mc}}{L} \cdot \Delta \dot{W}_0.$$

By substituting the last expression in (1) we obtain

$$\Delta \dddot{W}_0 + p_1 \Delta \ddot{W}_0 + p_2 \Delta \dot{W}_0 + p_3 \Delta W_0 = p_4 \sin\omega t + p_5 \cos\omega t. \tag{5}$$

Here

$$p_1 = \frac{2\eta}{m} + \frac{R}{L};$$

$$p_2 = \frac{RK_{en}}{Lm}\left(\frac{L}{R} + \frac{2\eta}{K_{en}} + K'\right);$$

$$p_3 = \frac{RK_{en}}{Lm}(1+K);$$

$$p_4 = \frac{R}{L} \cdot \frac{1}{m} F_0;$$

$$p_5 = \frac{\omega}{m} F_0;$$

$$K = \frac{K_{ind} K_{ce} K_{mc}}{RK_{en}};$$

$$K' = \frac{K_{ind} \varkappa K_{mc}}{RK_{en}}.$$

The stable oscillations of the autocompensating system are represented by a particular solution to Eq. (5):

$$\Delta W_0 = A \sin\omega t + B \cos\omega t,$$

If

$$A = \frac{p_4(p_3 - \omega^2 p_1) - p_5(\omega^2 - p_2)\omega}{(p_3 - \omega^2 p_1)^2 + (\omega^2 - p_2)^2\omega};$$

$$B = \frac{p_4(\omega^2 - p_2)\omega + p_5(p_3 - \omega^2 p_1)}{(p_3 - \omega^2 p_1)^2 + (\omega^2 - p_2)^2\omega}$$

This solution can be written as

$$\Delta W_0 = \sqrt{p_4^2 + p_5^2}\,[(p_3 - \omega^2 p_1)^2 + (\omega^2 - p_2)^2\omega]^{-\frac{1}{2}} \sin(\omega t + \varphi).$$

where

$$\varphi = \tan^{-1} \frac{p_4(\omega^2 - p_2)\omega + p_5(p_3 - \omega^2 p_1)}{p_4(p_3 - \omega^2 p_1) - p_5(\omega^2 - p_2)\omega}.$$

The elementary work dA done by force $F = F_0 \sin\omega t$ in displacing the envelope by $d(\Delta W_0)$ is

$$dA = Fd(\Delta W_0) = F_0\omega \Delta W_{0\,\mathrm{amp}} \sin\omega t \cos(\omega t + \varphi)\,dt.$$

The mean work done over one period will be

$$A_{\mathrm{m}T} = \frac{1}{2} F_0\omega \Delta W_{0\,\mathrm{amp}} \sin\varphi.$$

On the other hand the expenditure of the oscillatory energy in one second is

$$\Delta E_{\mathrm{sec}} = \frac{1}{4\pi}\omega^2 F_0 \Delta W_{0\,\mathrm{amp}} \sin\varphi = 325 \text{ erg}. \qquad (6)$$

By substituting in the expressions for $\Delta W_{0\,\mathrm{amp}}$ and φ instead of p_1 their values we obtain

$$\Delta W_{\mathrm{amp}} = F_0 \frac{\sqrt{\left(\frac{R}{L}\right)^2 + \omega^2}}{m} \left\{ \left[\frac{PK_{\mathrm{en}}}{Lm}(1+K) - \omega^2\left(\frac{2\eta}{m} + \frac{R}{L}\right)\right]^2 + \omega^2\left[\omega^2 - \frac{RK_{\mathrm{en}}}{Lm}\left(\frac{L}{R} + \frac{2\eta}{K_{\mathrm{en}}} + K'\right)\right]^2 \right\}^{-\frac{1}{2}}; \qquad (7)$$

$$\varphi = \tan^{-1} \frac{\frac{R}{L}\left[\omega^2 - \frac{RK_{\mathrm{en}}}{Lm}\left(\frac{L}{R} + \frac{2\eta}{K_{\mathrm{en}}} + K'\right)\right]\omega + \left[\frac{RK_{\mathrm{en}}}{Lm}(1+K) - \omega^2\left(\frac{2\eta}{m} + \frac{R}{L}\right)\right]\omega}{\frac{R}{L}\left[\frac{RK_{\mathrm{en}}}{Lm}(1+K) - \omega^2\left(\frac{2\eta}{m} + \frac{R}{L}\right)\right] - \omega^2\left[\omega^2 - \frac{RK_{\mathrm{en}}}{Lm}\left(\frac{L}{R} + \frac{2\eta}{K_{\mathrm{en}}} + K'\right)\right]}.$$

The angular frequency of the applied force $\omega = 126\ \mathrm{sec}^{-1}$.

Let us assume additional pressure gage parameters:

$$R = 20 \text{ ohm},\ L = 2 \text{ h},\ K = 10^4, \text{ and } K' = 10^4 \text{ sec}.$$

(A check by means of the Hurwitz criterion shows that such a highly sensitive closed system is stable).

In this case expressions (6), (7) and (8) provide the following values for the parameters, $\varphi = 176°$; $\sin\varphi = 0.07$; and $F_0 = 6 \cdot 10^5$ dyne and the required amplitude of envelope oscillations

$$\Delta W_0 = 6 \cdot 10^{-6} \text{ cm}$$

Hence, under conditions of vibration interference with a period of 0.05 sec and a power of 325 erg/sec the autocompensation system will retain the envelope with an accuracy of $6 \cdot 10^{-6}$ cm. At the same time the system must develop a periodic mechanical effort of the order of $6 \cdot 10^5$ dyne. In a pressure gage with a magneto-electric compensation mechanism the current flowing in the winding of the coil serves as the measure of gas pressure, i.e., of the compensating force. Noise fluctuations of the compensating force appear as current fluctuations with a period of 0.05 sec and an amplitude of $I_0 = F_0/K_{\mathrm{m\,c}} \approx 60$ ma. Such a current for the given pressure gage corresponds to a pressure of some 20 mm Hg.

In a strain pressure gage the envelope oscillates with an amplitude of some 10^{-2} cm whereas in autocompensated one its oscillations only amount to $6 \cdot 10^{-6}$ cm. This means that in the first place the hysteresis effects are present and in the second they are not. Fluctuations of the pressure-gage output signal can be suppressed by using a lagged measuring device. This arrangement is equally effective for both pressure gages. When measuring devices with the same degree of lagging are used in both case, the output signal will be cleared of fluctuations equally well in either case and both pressure gages will measure the same minimum pressure, providing their electronic circuits have the same sensitivity. The reliability of measurement will, however, be different since the reading of the strain pressure gage contains the effects of a slow fluctuation drift. Calculated estimations show that when a measuring device with time constant of 0.3 sec (the maximum for a vacuum gage) are used vibration errors in a strain pressure gage amount to $5 \cdot 10^{-2}$ mm Hg and in a autocompensated one to $3 \cdot 10^{-5}$ mm Hg.

Research workers complain of the difficulties caused by the high level of mechanical disturbances in strain pressure gages. For measurements of pressure of the order of 10^{-2} to 10^{-3} mm Hg such instruments must be placed on massive concrete foundations with vibration-absorbing lining. Autocompensated pressure gages are free from this defect and can be used for precision measurements both in laboratories and industry.

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APPLICATION OF STRAIN GAGES FOR MEASURING TORQUE

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In the papers published on strain gages for measuring torque, insufficient attention is paid to the investigation of a rational placing of gages from the point of view of compensating for the effect of additional factors, such as temperature, shear force, axle load and in the first place the bending moment.

When measuring torque the strain gage transducers are directed along the main tensions in rotation, i.e., at 45 or 135° to the axis of the shaft (Fig. 1). Each wire is placed along a helical line on the surface of the shaft and its position in the x, y, z system of coordinates is determined by parameters φ and Θ. Under the effect of bending, twisting and the shear force the shaft surface is in a complicated state of tension. For simplicity of calculations let us examine the middle wire ab of the transducer. The total change in its length can be expressed as

$$\Delta L = \int_a^b dl\varepsilon_{45°};\quad dl = \sqrt{2}\, r d\varphi;$$

$$\Delta L = \sqrt{2}\, r \int_a^b \varepsilon_{45°}\, d\varphi. \tag{1}$$

Here $\epsilon_{45°}$ is relative strain in the direction at 45° to the axis x. Using notations of Fig. 1 and integrating we obtain

$$\Delta L = \Delta L_{Mb} + \Delta L_{Mt} + \Delta L_Q = \frac{Pd^3(1-\mu)}{8\sqrt{2}\, EJ}\Big\{\sin(\varphi_2+\Theta) - \sin(\varphi_1+\Theta) - [\varphi_2\cos(\varphi_2+\Theta) - \varphi_1\cos(\varphi_1+\Theta)]\Big\} + \frac{\mathrm{Mt}\, d}{2\sqrt{2}\, G \overline{W}_\kappa}(\varphi_2-\varphi_1) + \frac{4.2\, Q}{\sqrt{2}\, G\pi d^2}\Big[\sin(\varphi_2+\Theta) - \sin(\varphi_1+\Theta)\Big]. \tag{2}$$

Here ΔL_{Mb} is the change in length due to the bending moment;

ΔL_{Mt} is the change in length due to twisting;

ΔL_Q is the change in length due to the shear force;

M_t is the torque;

Q is the shear force;

P is the load which produces the bending moment;

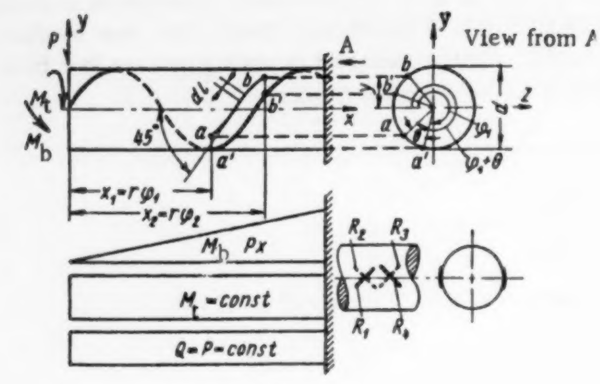


Fig. 1

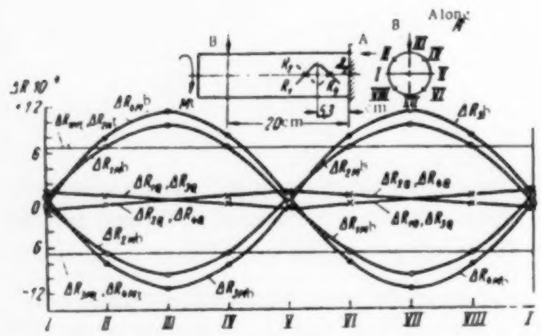


Fig. 2.

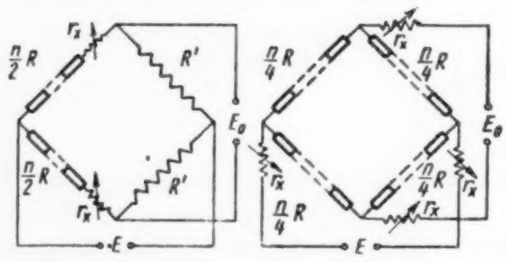


Fig. 3.

$\underline{d}$ is the shaft diameter; μ is the Poisson coefficient;

E is the modulus of elasticity of the 1st order;

G is the modulus of elasticity of the 2nd order;

J is the moment of inertia of the shaft cross section;

W_k is the moment of resistance of the shaft cross section.

In this analysis it is possible to ignore the variations in length due to temperature and axial load effects, since in the majority of cases these effects are compensated by means of a bridge circuit. Owing to the symmetry of stress curves with respect to the axis or the neutral plane of the shaft, the diametrically opposed transducers, for instance, R_1 and R_2 (Fig. 1) will be subjected to strains equal in their absolute values ($\Delta L_{Mb1} = |\Delta L_{Mb2}|$). A similar conclusion can be arrived at with respect to the strains due to the shear force ($\Delta L_{Q1} = |\Delta L_{Q2}|$). Twisting on the other hand causes in the respective wires of the two pairs of transducers (R_1, R_2 and R_3, R_4) strains with opposite signs, namely $\pm \Delta L_{Mt}$ and $\mp \Delta L_{Mt}$.

When the shaft is rotating and the bending and shear force remain in the same direction, each transducer is subjected to periodic tensile and compressive strains. On the basis of calculated data, with a transducer 2.2 cm long, a shaft 2.7 cm in diameter, P = 200 kg-wt and M_t = 500 kg-wt · cm, curves of variations in resistance ΔR with position (Fig. 2) were plotted assuming that the transducer wire resistance is unity per unit length. All the curves are symmetrical with respect to the axis. It is interesting to note that in positions I and V the following equalities hold $\Delta R_{1Mb} = \Delta R_{3Mb} = |\Delta R_{2Mb}| = |\Delta R_{4Mb}|$ if the bending moment varies linearly. This is due to the transducer being placed in this instance symmetrically above and below the neutral plane.

The problem of an efficient placing of the transducers on the shaft is solved according to manner in which the torque is varying (statically or dynamically).

In the majority of cases the following two versions of a bridge circuit are used (Fig. 3). Here $\underline{n}$ is the total number of transducers on the shaft, and this number must be even in order to obtain compensation; R is the transducer resistance which must be the same for all the transducers; r_x is the variation in the resistance of the slip ring; and R' is the external resistance. In one of the versions two operating (and at the same time compensating) arms are used (Fig. 3a); in the other all the four arms are operative (and at the same time compensating) (Fig. 3b). In the first version changes in the slip ring resistance r_x have a considerable effect on the reading stability. If the bridge is constructed according to the circuit of Fig. 3b, and the minimum number of transducers is taken as four, the variations of the slip ring resistance will produce a much smaller effect.

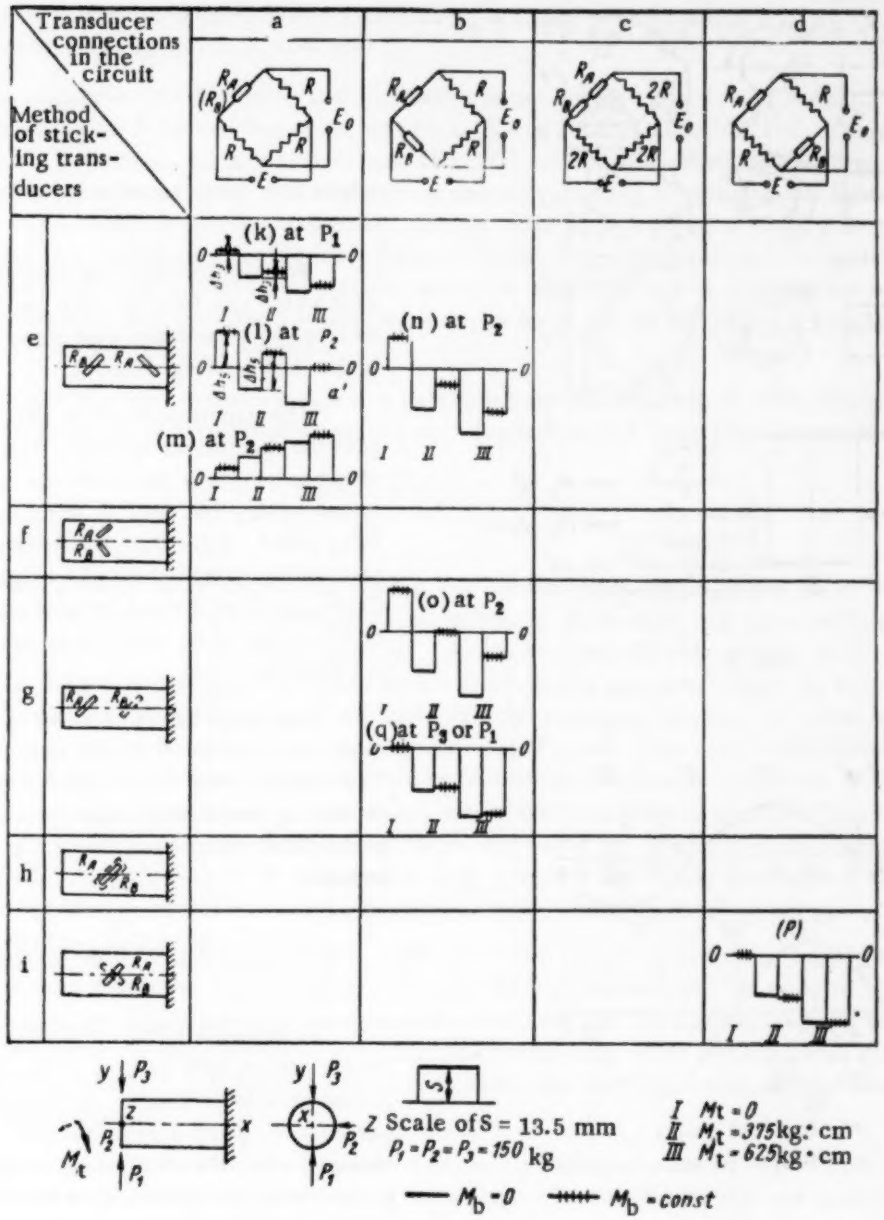


Fig. 4.

In practice two, four or more transducers are used for measuring torque in a static, oscillating or rotating condition. In order to evaluate the effect of associated phenomena on the value of torque, let us examine an example when only one working transducer is used, although in practice this never happens since one transducer alone cannot provide temperature error compensation. The total transducer resistance variation from all the extraneous factors is

$$\Sigma\Delta R = \Delta R_b + \Delta R_Q + \Delta R_{ax} + \Delta R_t,$$

where ΔR_b is the resistance variation due to the bending moment;

ΔR_Q is the resistance variation due to shear force;

ΔR_{ax} is the resistance variation due to the axle load;

ΔR_t is the resistance variation due to temperature.

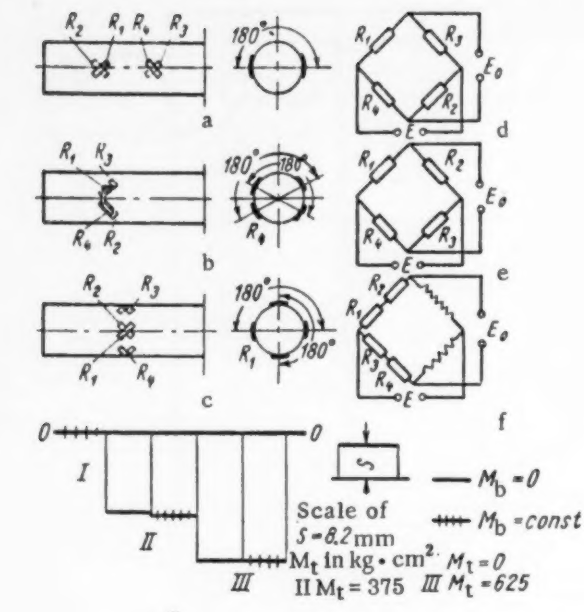


Fig. 5.

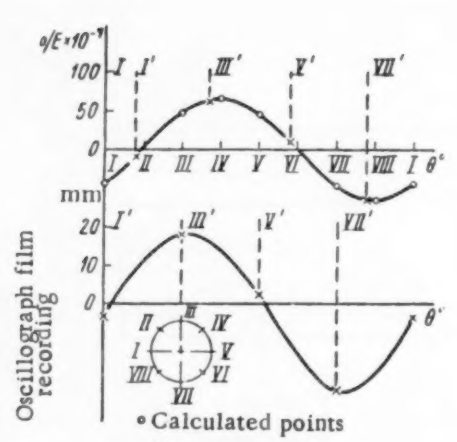


Fig. 6.

The relative error in determining torque will then be

$$\delta_1 = \frac{\Sigma' \Delta R}{\Delta R_K}, \tag{3}$$

where ΔR_k is the transducer resistance variation due to twisting.

For experimental purposes an equipment was used which provided the shaft under test, on whose surface the transducers were glued, with a known torque and bending moment.

The experimental data shown in Fig. 4 confirm the theoretical findings. The error due to bending either increases or decreases the measured value of torque by Δh_3 and Δh_5. In position a' the reading is zero, which means that the bending moment has completely balanced out the strain due to torque. Curve (k) shows a much smaller deviation since the middle point of R_A is in the neutral plane for bending from P_1.

The graph in Fig. 4 shows typical ways of using two transducers for the case when $R_A = R_B = R$. The relative error due to extraneous factors in measuring torque with transducers in positions e, f, g and h and bridge connection b is expressed by the formula

$$\delta_2 = \frac{0.5\,(\Sigma' \Delta R_A - \Sigma' \Delta R_B)}{\Delta R_K}. \tag{4}$$

By decreasing $\Sigma \Delta R_A - \Sigma' \Delta R_B$ the error is reduced; hence, both transducers R_A and R_B should be placed near to each other on one side of the shaft. Graphs e, f, g and h show that the best results are obtained when the transducers are in position e and f and connected according to circuit b. In the case under consideration torque produces strains in R_A and R_B opposite in sign, thus precluding the use of bridge circuits c and d, since in circuit d we have $E_0/E = -\Delta R_k^2/(4R^2 - \Delta R_k^2) \approx 0$ (where E_0 is the bridge unbalance voltage and E is the supply voltage), and in circuit c the increments ΔR_k produced in R_A and R_B balance each other out, thus, reducing the signal due to torque practically to zero. Graphs L, M and N show the effect of bending on the torque measurements when one or two transducers are used in the least favorable positions. Dividing (4) by (3) we have

$$\frac{\delta_2}{\delta_1} = 0.5\left(1 - \frac{\Sigma' \Delta R_B}{\Sigma' \Delta R_A}\right).$$

It will be seen from this expression that in order to increase the accuracy of measurement it is necessary to connect into the bridge circuit a second transducer which is strained by $\Sigma' \Delta R_B$ approaching in value $\Sigma' \Delta R_A$. If the value in the brackets is less than one, $\delta_2/\delta_1 < 50\%$, i.e., the error of measurement with two transducers is only half that with one transducer. For graphs L, M and N with M_t = 625 kg-wt • cm, $\delta_1 = 100\%$ (in the case of one transducer) and $\delta_2 = 35\%$ (in the case of two transducers).

Graph O in Fig. 4 shows a considerable effect of bending on torque measurements and graph Q shows that deviations $\Sigma' \Delta R$ are close to zero, since theoretically $\Sigma'\Delta R_A = \Sigma'\Delta R_B$ in this position and $\delta_2 = 0$. This characteristic can be utilized in static measurements.

The last row (41) shows that in turning it is impossible to use circuit b since $\Delta R_{kA} = \Delta R_{kB}$. If measurements are made with circuit d the bending effect will be $E_0/E = -\Sigma'\Delta R^2/(4R^2 - \Sigma'\Delta R^2) \simeq 0$. Graph (P) in Fig. 4 clearly illustrates this condition, but in it temperature and axial loading will effect the readings of M_k. In our case at a temperature of $t° = \text{const}$, $M_t = 500$ kg-wt·cm and axial loading force $P_{ax} = 300$ kg-wt, the error amounts to 10%; if the temperature remains constant and the axial force is small or absent, the placing of transducers in positions i and connecting them according to circuit d will produce more accurate results than the remaining versions in static and oscillatory conditions of measurements, when slip rings are not used. Positioning i with connections c provides the same accuracy as for d, but the sensitivity is smaller since, in rotation, only one arm of the bridge is operative.

Different ways of placing transducers $R_1 = R_2 = R_3 = R_4 = R$ are shown in Fig. 5. The formula for determining the relative error due to extraneous factors in measuring torque with the bridge circuit shown in d is

$$\delta_4 = \frac{\Sigma'\Delta R_B^2 - \Sigma'\Delta R_A^2}{4R^2} \Big/ \frac{\Delta R_K}{R} \simeq 0. \tag{5}$$

Here $\Sigma'\Delta R_B^2 = | \Sigma'\Delta R_3\ \Sigma'\Delta R_4|$; $\Sigma'\Delta R_A^2 = | \Sigma'\Delta R_1\ \Sigma'\Delta R_2|$. In our example with $M_t = 500$ kg-wt·cm and $P = 200$ kg-wt the calculated value of $\delta_4 = 0.014\%$ as it is shown in Fig. 2. If the light spot in an oscillograph is deflected for $M_t = 500$ kg-wt·cm by 30 mm, deflection due to bending will only amount to $30 \times 0.014\% = 0.0042$ mm, i.e., 4.2 μ; it is difficult to notice such a deflection in practice. Figure 5g shows the curve for P = 150 kg-wt in any direction, obtained experimentally with the arrangement of Fig. 2. Here the error due to bending is quite small, but nevertheless larger than the calculated value. This can be explained by the effect of the mechanical hysteresis, inaccuracy of setting, distortions of the electrical circuit, etc. It can be considered in practice that δ_4 is equal to zero. Hence, any one of the arrangements shown in Fig. 5 (a, b or c) can be used, but from the operational point of view those shown in b and c are more convenient, since they occupy a smaller space along the shaft axis. With a shaft of a small diameter and a long transducer it is more convenient to use arrangement a, since there will be insufficient space in arrangements b and c.

Circuit e is unsuitable for measuring torque, since the values of ΔR_k balance out in neighboring arms of the bridge. Such a circuit does not register torque, but only the bending moment. In order to check the theoretical considerations, we have plotted for above circuit calculated and experimental curves, which represent the effect of bending when the shaft is rotated (Fig. 6). The curves only differ by their phase shift due to distortion in the electrical circuit. It is possible therefore to assert that the theoretical calculations provide qualitatively correct results.

In circuit f of Fig. 5 the extraneous effects are completely balanced out, i.e., $\delta_4 = 0$, but in rotational measurements the contact resistance of the slip rings has a large effect on the stability of operations. In such instances research workers avoided using slip rings in order to eliminate the effect of contact resistances on the stability of operation, but this introduces considerable difficulties of operation.

It is advisable to use circuit d which practically eliminates errors due to extraneous factors in measuring torque and greatly reduces the effect of the instability of slip-ring contact resistances.

The use of a set of many transducers made of foil for measuring torque is mentioned in technical literature; this is, however, only a variation of circuits with 2 or 4 transducers. From the point of view of accurate measurements this arrangement does not provide any advantages; it sometimes reduces the sensitivity owing to the mismatching of the amplifier.

ACCURACY OF MACHINES FOR TESTING TENSION AND COMPRESSION IN METALS

V. G. Ulegin

The basic characteristics of the same metal recorded on a chart can differ considerably from each other according to the conditions of testing, in particular owing to differences in the relative speed of deformation of the sample under test, and the inertia of the stirrup link.

One of the factors affecting the relative nominal speed of deformation of the sample under test and the inertia of the machine is the stiffness of the machine and the sample.

We shall take stiffness K_M of the machine, determined under conditions of strain in the ends of the sample, to be the ratio of effort P_n applied to the ends of the sample to the deformation W_n (elastic and contact) caused by this effort.

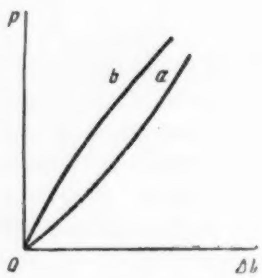


Fig. 1.

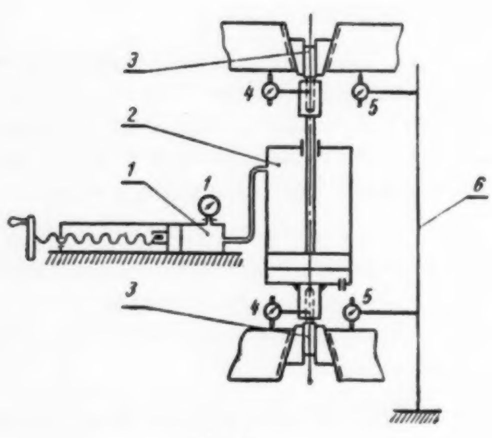


Fig. 2.

The compliance, or its opposite, the stiffness, of a machine unit will consist of the elastic and contact deformations of its details. Contact deformation usually does not follow a linear law.

The closer drawing together of the details with rising loads is much more pronounced at low pressure than high ones.

In a number of instances the contact compression curves a expressed in load against deformation coordinates (Fig. 1) are concave (compliance in the gripping jaws) i.e., the stiffness increases with load. There are also cases when curves, as in b, are convex, i.e., stiffness falls with load, which is connected with a preliminary tightening of all the joints in the machine.

Hence, the compliance of the machine is determined by the sum of the elastic $\sum_{i=1}^{n} W_i^c$ and contact $\sum_{i=1}^{n} W_i^c$ compliances of the units which constitute the machine:

$$W_n = \sum_{i=1}^{n} W_i^e + \sum_{i=1}^{n} W_i^c. \tag{1}$$

The compliance of the system W_s is determined by the formula

$$W_s = \sum_{i=1}^{n} W_i^e + \sum_{i=1}^{n} W_i^c + W_{spl} \tag{2}$$

Where W_{spl} is the compliance in the sample with load P_n.

The relation between the nominal relative speed of deformation and stiffness of the machine can be expressed by the formula

$$V_d = \frac{V_{ag}}{l_0} \cdot \frac{K_M}{K_M + K_{spl}} \quad \text{or} \quad V_d = \frac{V_{ag}}{l_0} \cdot \frac{W_{spl}}{W_n + W_{spl}}, \tag{3}$$

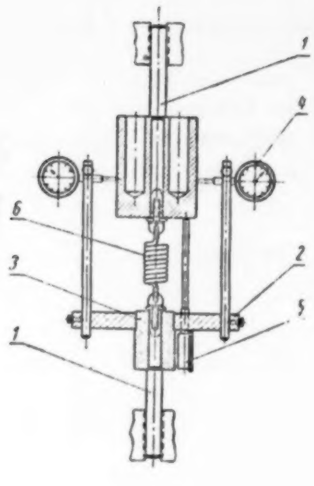


Fig. 3.

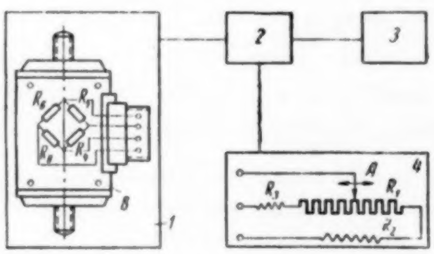


Fig. 4. 1) Electric strain gage connected in parallel with the standard; 2) amplifier 8AN47M; 3) oscillograph; 4) slide wire which records the movement of the stirrup link.

where V_d is the nominal relative speed of deformation of the sample;

$V_{ag.}$ is the speed of active gripping;

K_M is the stiffness of the machine;

K_{spl} is the stiffness of the sample;

l_0 is the gage length of the sample.

From an analysis of (1) and (3) it is possible to arrive at the conclusion that the nominal relative speed of deformation V_d of the sample will be affected both by the elastic and contact compliances of the machine.

It follows from (2) that the starting and nature of the oscillations of the stirrup link as the part of the machine with the greatest inertia will in the main depend on the compliance of sample W_{spl} and the contact compliance of the machine

$\sum_{i=1}^{n} W_i^c$, since their nonlinear variations cause an uneven displacement of the stirrup link. Moreover the starting of the machine with an almost final speed of loading considerably affects the rise of stirrup link oscillations.

It follows from the above that if the mean coefficient of stiffness of the machine P_n/W_n and the curve which determines the error mainly due to the compliance and inertia of the machine are determined, it will be possible to judge the accuracy and reliability of the basic characteristics, recorded on a chart, and the constructional and technological properties of the machine under test.

With the object of determining the mean coefficient of stiffness and a systematic investigation of the effect of stiffness of the machine on the recording of the basic mechanical characteristics of samples, an equipment whose diagram is given in Fig. 2 was developed. The equipment consists of press 1 and traction member 2 of a hydraulic dynamometer DPM.

In order to be able to fix and exchange butt ends 3 the bottom of the traction-member cylinder was reconstructed and the threaded end of the piston rod had a coupling adaptor screwed onto it.

Member 2 with its rigidly connected butt ends was fixed in the jaws of the machine under test. Extensometer 4 was fixed to the traction member and extensometer 5 to post 6 which was mounted on the foundation of the machine. The deformations were measured with loading obtained by means of the piston press 1. The load was read off the dynamometer scale of the machine and manometer of the press.

The accuracy of measurement was evaluated by comparing the results obtained by means of this equipment and by the sectionalized method of using extensometers mounted on the post with their measuring rods resting against various parts of the machine.

As the result of these tests it was found that the accuracy of measurements did not exceed 1.5%.

It was also found by this method that the coefficient of stiffness of the machine varies with the drifting of the gripping axis of the sample.

The value of the drift was determined by the equipment shown in Fig. 3.

When the equipment was fixed in the wedge jaws of the machine, butt ends 1 were used.

Disk 2 press fitted into collar 3 turned together with extensometers 4 and 5 round the butt end during testing. At high loads spring 6 was replaced by a smooth steel rod.

Extensometer 4 indicated the drift of the gripping axis of the sample, and extensometer 5 parallelism between the two jaws.

It was established by means of this equipment that the displacement of the axis in the tested machines varied between 1 and 5 mm. At the same time the top moving crossarm and, hence, also the bottom one vibrated during loading; this was measure by means of two extensometers fixed to the top crossarm of the moving frame of the machine.

The stiffness of the machine- sample system was determined from the formula

$$\frac{1}{K_s\,M} = \frac{1}{K_M} + \frac{1}{K_{spl}},$$

where K_s is the stiffness of the machine — sample system;

K_m is the stiffness of the machine;

K_{spl} is the stiffness of the sample.

The speed of displacement of the machine components is affected by changes during testing in the stiffness of the sample as the results of its mechanical properties, and variations in the sitffness of the machine due to technological and design factors.

Since the machine members move with acceleration, forces of inertia arise which produce the discrepancy between the actual characteristics of the sample and those obtained on the large recording chart.

The error due to the inertia of the machine members, mainly that of the stirrup link, was determined by comparing the actual extension and compression curves which was taken as a standard with those obtained by means of the slide wire, mounted in the body of the dynamometer, the amplifier and the oscillograph (Fig. 4).

The curve obtained by means of the electric strain-gage head B which is mounted in series with the stiff sample in the jaws of the machine was taken as a standard.

The equipment was adjusted in such a manner that the indications of the slide wire and the electric strain gage, recorded on the oscillograph screen as two straight lines, coincided. Next the stiff sample was replaced in the jaws of the machine by a sample made of tempered steel 2 or 4.

By means of the above three instruments it was established that it is impossible to compare the basic mechanical characteristics of samples recorded on charts of different types of machines.

The designing of machines without taking into account the inertia and stiffness make it impossible to choose optimum speeds of active gripping. That is why existing machines with stirrup links cannot provide, under certain conditions of measurement, errors below ± 1% of the measured force.

Tests have shown that the error of existing machines according to their inertia, stiffness, speed of active gripping and load amounted to anything between 0 and 63% of the measured quantity.

AN INSTRUMENT FOR CHECKING NOISE IN ANTIFRICTION BEARINGS

B. E. Bolotov

The existing methods of checking bearings for noise by means of a microphone are in fact designed for laboratory use only and are unsuitable for production measurements.

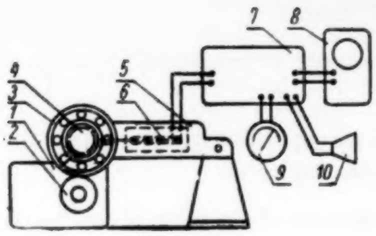


Fig. 1.

Number of the bearing	Arithmetic mean of 5 measurements	Number of the bearing	Arithmetic mean of 5 measurements
1	4.2	6	5.0
2	4.5	7	4.5
3	6.5	8	4.8
4	4.0	9	7.0
5	4.5	10	4.3

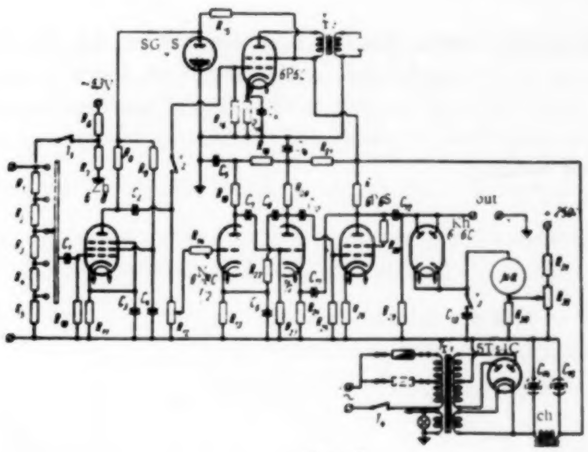


Fig. 2.

The instrument here described is designed for comparative checking of bearing noise under shop conditions by measuring their vibration. The noise is not evaluated by "listening" with a microphone, but is "felt" with a piezoelectric transducer consisting of a barium titanate crystal, which measures vibrations in the audio range; external noise is therefore, not registered by the set.

A rubber pulley 2 is mounted on the axle of a 20 w, 2550 rpm motor 1 type VN-2 (Fig. 1).

The inner race of the tested bearing 3 is pushed over split socket 4, which is rigidly fixed to the end of lever 5. The lever is made hollow inside to hold the piezoelectric transducer 6. In order to receive the vibrations of the bearing, the plate of the piezoelement is connected to it by means of a steel rod. There must be a given size split socket for each type of bearing.

The piezoelectric transducer is connected to amplifier 7 which can feed, if required, an oscillograph 8, a milliammeter 9 and a loudspeaker 10.

The amplifier schematic is given in Fig. 2. One of its channels (tubes 6Zh8, 6N8, 6P6 and 6Kh6) is used for feeding the milliammeter or the oscillograph and the other (tubes 6Zh8 and 6P6) for the loudspeaker.

Since the set can measure noise of different types of bearings, the amplifier has at its input a potential divider (resistors R_1, R_2, R_3, R_4 and R_5). By means of the potential divider it is possible to adjust the gain to 100, 300, 1000, 3000 and 10000.

It is possible to calibrate the gain of the amplifier by means of an ac current fed through a divider (R_6 and R_7) and tumbler switch T_1. Before calibration the amplifier is connected to the mains for half an hour in order to warm up, it is then set to a gain of 100 (minimum gain) and the tumbler switch T_1 operated.

During calibration the loudspeaker must be disconnected. If the overall gain has not changed, the pointer will remain at a calibration marked "K"; in case the pointer has drifted the gain can be readjusted by means of potentiometer R_{12}.

The piezoelectric transducer is connected to the socket marked "Input."

For monitoring the noise of the bearing during testing a loudspeaker can be connected by tumbler switch T_2.

For convenience of observation the milliammeter can be shunted by capacitor C_{13} by means of tumbler switch T_3; in this case the instrument will read the mean value of the bearing noise.

In order to determine the stability of this method, several measurements of the noise of one bearing were made at different times; the results thus obtained did not differ from each other by more than 5%.

Bearings were graded for noise at the 4th State Bearings Plant by means of above equipment in the following manner. Ten bearings were selected with different noise levels by the plant measuring laboratory. All the bearings were numbered consecutively from one to ten. Two of them, Nos. 3 and 9, were rejected by the Technical Inspection Department on account of high noise. The bearings were tested on the set, whose readings in relative noise units are given in the table.

It will be seen from the table that bearing No. 3 has a noise level of 6.5 and bearing No. 9 of 7.0; all the other bearings have noise levels not exceeding 5 units. A line should be drawn on the instrument dial at figure 5. The instrument will then be ready for mass-production checking of bearings for noise. If the pointer deflects beyond the line, the noise level is considered excessive and the bearing is rejected. With a little practice it takes some 3 seconds to check one bearing.

MEASUREMENTS OF MASS

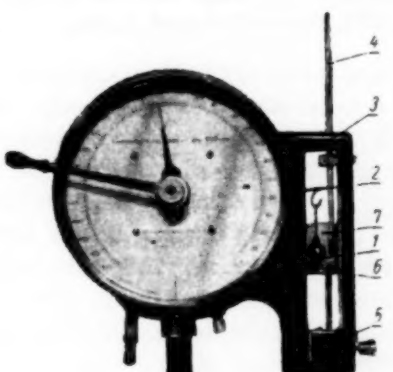
A QUICK METHOD OF DETERMINING THE CONCENTRATION OF SOLUTIONS

V. N. Sokolov

When concentrations of solutions are determined by their density measured by means of hydrometers, not less than 100-150 cm^3 of liquid is required. It is not always possible to collect such an amount of liquid for analysis, especially in laboratory investigations.

Determining concentration of solutions by means of pycnometers requires less liquid, but it involves a considerable amount of labor due to repeated weighing on analytical balances.

For a speedy analysis of solutions, with a sufficient accuracy and requiring small amounts of liquid, it is possible to adapt the torsion scales produced by the "Tekstil'pribor" plant (Moscow).



If torsion scales are used to weigh an object, for instance, a ball immersed in one of the liquids which form the solution, the weight of the ball can expressed as

$$A_1 = G_b - V_b d_1; \tag{1}$$

if the ball is weighed in a heavier solution

$$A_2 = G_b - V_b d_2, \tag{2}$$

where A_1 and A_2 are readings of the torsion scale, g;

G_b is the weight of the ball in air, g;

V_b is the volume of the ball, cm^3;

d_1 and d_2 is the density of the pure liquids which form the solutions, g/cm^3.

The absolute error in determining the density of the solution on torsion scales is

$$\Delta = 0.001\frac{d_1 - d_2}{A_2 - A_1}. \tag{3}$$

Hence, in order to attain greater accuracy it is necessary to have the largest possible difference $(A_2 - A_1)$. In this instance it is most convenient to take $A_1 = 0.1$ g and $A_2 = 0.5$ g. For these values of A_1 and A_2 the weight and volume of the ball are calculated from (1) and (2).

By taking one of the liquids forming the solution (for instance, the heavier) as a standard, it is possible to express the density of the solution of any degree of concentration as

$$d = d_1\frac{G_b - A}{G_b - A_1}, \tag{4}$$

where A is the reading of the scale (in g) corresponding to the density of that liquid.

The concentration of the solution is determined from its density by means of special tables. By calibrating the scales in terms of the table it becomes possible to reduce considerably the time taken by the analysis.

If the analysis is made at a temperature distinct from 20°C, the density of the liquid is calculated from (4) with a temperature correction. By means of a suitable selection of the weight and volume of the ball, the torsion scales can be adapted for determining the density and concentration of any solutions.

In the Leningrad Technological Institute torsion scales were adapted for measuring concentrations of ethyl alcohol solutions in water (see figure). A hollow ball 1 is suspended from the arm 2 of a torsion scale by a thin wire, whose volume compared with that of the ball is negligible. Thermometer 4 for measuring the temperature of the liquid is placed on the level of the ball through the hinged cover of the scale. A device 5 with a small cup 6, on which beaker 7 with the tested liquid is placed, is mounted at the bottom of the scale cabinet. When the beaker is lifted the ball and the thermometer are immersed in the solution. The steady-state reading of the scale indicates the density and concentration of the solution.

In determining the density of alcohol in water solutions by means of the torsion scale with a ball weighing 1.9 g and a volume of 1.8 cm^3 it is possible to attain an accuracy of 0.0006 g/cm^3, which corresponds to a variation of the solution concentration of 0.5% (by weight).

The hollow ball was made by depositing copper on a wax-graphite mould. The wax was subsequently heated and drained through a small hole drilled in the ball and the hole soldered with tin. After nickel plating the ball its weight was adjusted to the calculated value by varying the amount of soldered tin.

It is also possible to make a hollow glass ball on a platinum suspension. In this case the external surface of the ball is silver plated and the weight of the ball is adjusted by nickel plating the silver.

The glass beaker for holding the solution was 32 mm in diameter and 40 mm high. The amount of liquid required for the analysis was 20 ml. The time taken for the analysis at 20°C does not exceed 1 min.

THERMOTECHNICAL MEASUREMENTS

A GOLD-PLATINUM THERMOCOUPLE

A. M. Sirota and B. K. Mal'tsev

In research work it is often necessary to use thermocouples for precise measurements below 630°C, for instance, for measuring small temperature differences, or when it is necessary to decrease the dimensions of the sensitive elements thus precluding the use of platinum resistance thermometers.

The accuracy of measurement will in this case be limited by the thermoelectric homogeneity and stability of the materials forming the thermocouple. Platinorhodium – platinum thermocouples do not possess these properties to the full. Purified platinum is a very homogeneous and stable material, but platinorhodium is usually insufficiently homogeneous; instances of instability of plantinorhodium at 400-600°C are described [1].

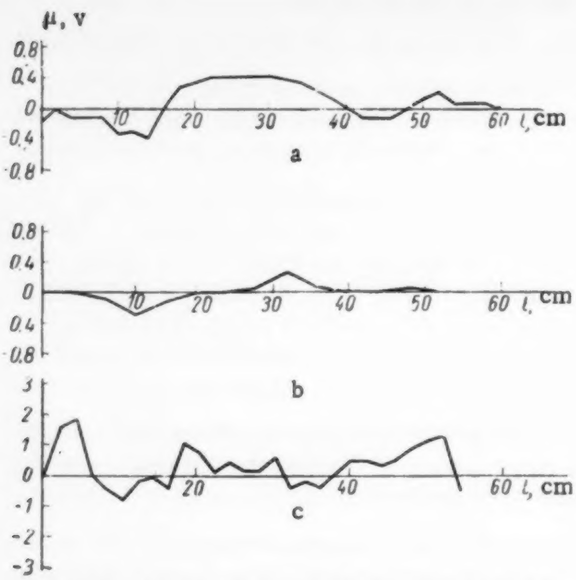
It is known that the thermoelectric homogeneity of pure metals is higher than that of alloys [2]. Hence,it was decided to investigate in the temperature range under consideration the platinum-gold thermocouple in order to see what are the advantages of this pure-metal thermocouple as compared with the normal platinorhodium-platinum one.

Gold was purified and drawn to a diameter of 0.2 mm in A. A. Rudnitskii's Laboratory of the Acad. Sci. USSR. After the gold wire was drawn it was washed in alcohol, distilled water, boiled in hydrochloric acid and then again washed in distilled water. Chemically pure platinum wire PT1 (GOST 8588-57) of 0.2 mm in diameter with a ratio $R_{100}/R_0 > 1.392$ (according to the factory certificate) and the platinorhodium delivered with it were similarly washed except that the hydrochloric acid was substituted by nitric acid. From the wire thus purified 4 thermocouples were made, whose calibration is described below. Before making up the thermocouples a comparative analysis was made of the thermoelectric homogeneity of several samples of the wire which was to be used. For this purpose a heater with an asymmetrical temperature field [3] was passed along the wires, whose ends were connected at their cold junctions to a potentiometer. Measurements were made at the maximum temperature of the heater of 530°C. Before the homogeneity tests the platinum and platinorhodium wire was annealed in air at a temperature of 600°C, which corresponds to a crimson color, by passing through it an electric current for one hour. The gold wire was annealed for two hours at a temperature of some 700°C by passing an electric current through it. The temperature was gaged by the resistance of the wire.

It will be seen from the graphs (see figure) that the irregularities in platinum did not exceed 0.4 μv, in gold 0.3 μv whereas in platinorhodium they reached 1.5 μv. The total nonhomogeneity of thermocouples as a whole expressed in terms of temperature amounted to 0.2°C for platinorhodium thermocouples and 0.04°C for gold-platinum thermocouples.

Thermocouples were made of wire which had not been annealed and taken from different ends of a coil. They were soldered with gold, armored by quartz capillary tubing and enclosed in thin-walled quartz sleeving of 3 mm external diameter. The armoring and sleeving was preannealed at a temperature of 800°C. The thermocouples were assembled in such a manner as to eliminate completely the possibility of the wire bending in the region of an abrupt change of temperature. After manufacture the thermocouples were annealed in pairs together with their lead-in wires in a long quartz tube which was slowly drawn through a muffle. The gold-platinum thermocouples were annealed for 2 hours at 500°C, the platinorhodium-platinum ones for one hour at 800°C. This type of annealing of the platinorhodium-platinum thermocouples is adequate for removing any plastic strains [4].

The relations between the thermal emf and temperature in gold-platinum thermocouples was studied by



Analysis of the thermoelectric homogeneity of thermocouple materials: a) platinum; b) gold; c) platinorhodium.

Calibration of a Gold-Platinum Thermocouple with the Cold Junction at 0°C

Temperature of the hot junction, °C	Thermal emf, μv
200	1839.2
300	3133.4
400	4622.1
500	6285.4
550	7180.1

comparing their readings with those of standard platinum resistance thermometers in a salt thermostat. The gold-platinum and two platinorhodium-platinum thermocouples were calibrated simultaneously.

In order to check the stability of the thermocouples, the thermostat was kept during calibration for a long time at 500°C and then the thermocouples were again measured at several points. In all, measurements were made at 30 points in the range of 190-550°C. The results of these measurements show that for both the gold-platinum thermocouples the emf readings obtained before their prolonged heating at high temperature differed a little from those obtained after the heating. This is probably explained by the insufficient duration of annealing. Further prolonged heating did not change their calibration and the gold-platinum thermocouples were assumed to be completely stable. A few of the original readings were disregarded in subsequent treatment.

The difference in readings of the gold-platinum thermocouples in all the 30 points measured did not exceed 0.2 μv (0.013°C). The average deviation of these thermocouples amounted to 0.08 μv. The maximum deviation for the platinorhodium-platinum thermocouples was 1 μv (0.1°C) and the mean deviation was 0.6 μv. At several points measurements were made with varying temperatures along the thermocouples wires, and these variations did not affect the reading of the gold-platinum thermocouples, but produced considerable variations in the readings of the platinorhodium-platinum thermocouples.

The readings of two gold-platinum thermocouples (in μv) were averaged and represented by the following formulas:

from 190 to 326°C

$$\varepsilon=202.1+2.8564t+37.181\cdot10^{-3}t^2-6.3814\cdot10^{-5}t^3+$$
$$+5.57\cdot10^{-8}t^4;$$

from 326 to 550°C

$$\varepsilon=-217.0+8.2298t+10.15\cdot10^{-3}t^2-12\cdot10^{-7}t^3.$$

At a temperature of 326°C both formulas provide values of thermal emf and their derivatives $d\epsilon/dt$ which agree well with each other. The mean deviation of the average measured values from the calculated ones amounts to 0.09 μv (about 0.006°C), which approaches the limit of the potentiometer equipment sensitivity. The maximum deviation of the measured from the calculated values amounts for some of the thermocouples to 0.02°C.

The table below shows the calculated values of thermal emf for the tested gold-platinum thermocouples.

The relations between the thermal emf and temperature for one of the tested platinorhodium-platinum thermocouples could be represented by two cubic parabolas.

SUMMARY

Since the homogeneity of gold is much higher than that of platinorhodium, the gold-platinum thermocouples provide considerably more accurate temperature measurements than platinorhodium-platinum thermocouples. The high degree of homogeneity of gold is especially valuable when small temperature differences are measured. Another important advantage of the gold-platinum thermocouples as compared with the platinorhodium-platinum ones is their higher thermal emf and lower electrical resistance. The defects of the new thermocouple are its high thermal conductivity, tendency to acquire plastic strains and the low melting point of gold as compared with platinorhodium. These defects are absent in another thermocouple made of pure metals, the rhodium-platinum thermocouple, which we propose to analyse in the future.

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COMPARISON OF LOW-TEMPERATURE SCALES OF PLATINUM RESISTANCE THERMOMETERS

D. N. Astrov, M. P. Orlova, P. G. Strelkov and D. I. Sharevskaya

The 1958 session of the Consultative Committee on Thermometry recommended to compare platinum resistance thermometers in the temperature range below 90°K.

Complying with this recommendation the All-Union Scientific Research Institute of Physicotechnical and Radiotechnical Measurements and the National Physical Laboratory (London) decided to compare their thermometers. We have completed the testing of the British platinum resistance thermometer which was sent us by the NPL. The thermometer was calibrated at the triple point of water, and at the boiling points of water, oxygen and hydrogen. The calibration results point to the high purity of the British platinum; moreover its characteristic approaches that of platinum IKh-6 from which our group standard is made.

$R_{0°C}$	$R_{100°C}/R_{0°C}$	$R_{90.19°K}/R_{0°C}$	$R_{20.39°K}/R_{0°C}$
24.3674 ohm	1.39250	0.243919	0.004534

The thermometer was compared with the group standard at 35 temperature points in the range of 10 to 90°K. Comparisons were made in an adiabatic cryostat with a temperature rate of change of $1 \cdot 10^{-4}$ degrees/min.

The experimental characteristic of the British thermometer obtained on the IKh-6 scale was compared with the NPL calibration calculated from the "Z-function" tables of the National Bureau of Standards (USA) [1] and corrections to it [2]. This method of comparison is completely satisfactory for this platinum, although it greatly narrows the range of comparable types of platinum which can be used in this temperature range. Thus, for instance, our commercial type platinum "Pobeda" which is close to the British in its purity ($R_{100°C}/R_{0°C}$ = = 1.39243), does not satisfy the additional criterion and, hence, the calibration of individual thermometers made

with it cannot be calculated according to the method suggested by the NPL. Moreover the above- cited method of corrections was developed for the temperature range of 90 -- 20°K, whereas the platinum resistance thermometer scale below 20°K is at present undoubtedly required.

The differences between the practical scale UKh-6 and the calibration of the NPL thermometer according to [1] and [2] between 90 and 20°K does not exceed 0.01°, i.e., it is of the same order as the difference of our practical scale IKh-6 from the thermodynamic one.

In order to complete comparing the temperature scales below 90°K it is necessary to compare directly the NPL and our scales since they are based on primary measurements with gas thermometers.

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ELECTRICAL MEASUREMENTS

PRECISION MEASUREMENT OF AC ENERGY

A. M. Ilyukovich

When checking ordinary electricity meters, measuring electrical energy in large power stations and in some special testing it is necessary to measure with great precision the energy in single and three-phase circuits. Measuring methods which provide an accuracy of 0.05 to 0.1% do exist, but they are complicated and they are only practicable under laboratory conditions. The best types of foreign-made standard induction electricity meters are highly stable, but their subsidiary errors due to heating-up, ambient temperature changes, variations in the mains frequency, are sufficiently large and the accuracy of these meters does not exceed 0.3%.

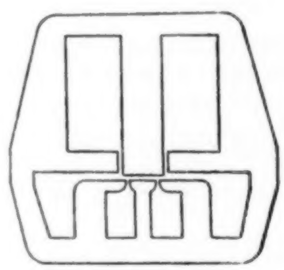

Fig. 1.

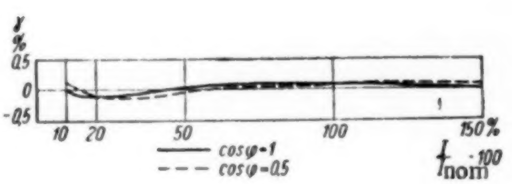

Fig. 2.

The All-Union Scientific Research Institute of the Committee of Standards, Measures and Measuring Instruments has completed the development and produced a test batch of single-phase electricity meters V-3 with an error of ± 0.3% for cos φ = 1 and ± 0.4% for cos φ = 0.5. Meters type V-3 are designed for checking grade 2.0 and 2.5 electricity meters and work on the constant load principle, the current in the series circuit remaining equal to its nominal value (5 amp) for all the load conditions at which the commercial electricity meters are tested. In order to obtain the constant load condition the meter is provided with a multitap current transformer and a multitap voltage autotransformer.

Figure 1 shows a rotor core lamination developed by the author of this article for the V-3* electricity meter. The core is not sectionalized and the series winding has to be wound by pulling the copper tape through the openings in the core; this manufacturing difficulty is justified by the reading stability thus achieved.

The rotor is designed so as to achieve the maximum quality factor with respect to spontaneous heating:

$$K_g = \frac{M_t}{\sqrt{P_U P_I}}, \tag{1}$$

where M_t is the torque;

P_U and P_I is the power dissipated in the parallel and series circuits, respectively.

The quality coefficient according to (1) amounts to 35 g-wt·cm/w for the rotor of the V-3 meter as compared with the normal figure of 6-10 g-wt·cm/w. This circumstance makes it possible to provide a large torque (6 g-wt·cm as against the normal 3.5-4.5 g-wt·cm) with a small dissipation in the parallel and series circuits (0.3 and 0.1 w, respectively). Thus, the variation of errors due to spontaneous heating has been almost completely eliminated in the V-3 meter both at cos φ = 1 and cos φ = 0.5.

*The development of the general circuit and construction of the B-3 electricity meter was made by N. G. Vostroknutov.

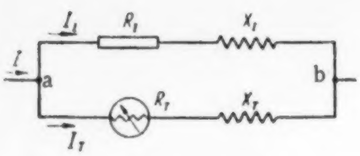

Fig. 3. Series circuit of the meter with full temperature compensation: U and I) mains voltage and current; Φ_I and Φ_U) effective fluxes of the series and parallel circuits; ψ) phase difference between fluxes Φ_I and Φ_U; for the case of $\cos\varphi = 1$ (Fig. 4) $\psi = 90°$; X_I) inductive reactance of the series winding; R_I) building-out resistance of the series winding (for simplicity it has been assumed that it includes the resistance of the winding itself); R_T) thermistor resistance; X_T) additional inductive reactance.

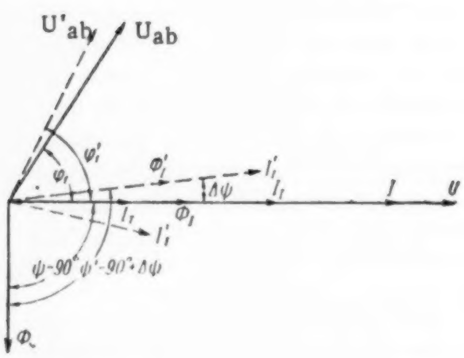

Fig. 4. Vector diagram of the circuit shown in Fig. 3 (the notation is the same as in Fig. 3; dashed letters denote quantities referred to the higher temperature).

When the load is varied in the limits of 10 to 150% of the nominal value the load curve of meter V-3 (Fig. 2) does not deviate by more than ± 0.1% for $\cos\varphi = 1$ and ± 0.15% for $\cos\varphi = 0.5$. Thus, the measuring element of the meter can be used for constructing multirange standard meters and for the manufacture of precision electricity meters used in large power stations.

The effect of voltage variations is compensated in the V-3 meter. For this purpose the well-known [2] method of introducing in the path of the nonoperative magnetic flux a parallel circuit of saturating segments was used. A voltage change of ± 5% produces an error in the V-3 meter reading of not exceeding ± 0.1%.

The problem of reducing the effect of frequency and ambient temperature variations on the V-3 meter has not been solved. The temperature coefficient of meter V-3 is approximately 0.1% per 1°C for $\cos\varphi = 1$ and a little smaller for $\cos\varphi = 0.5$. Frequency variations of ± 0.5 cps produce reading errors of approximately 0.2%.

The problem of compensating frequency and temperature errors of induction meters was solved by the author in developing a three-phase standard meter. This meter had a temperature-compensating circuit proposed by the author (Fig. 3), based on use of thermistors with a negative temperature coefficient [3].

Figure 4 shows a simplified vector diagram which explains the principle of operation of the circuit in Fig. 3.

In order to make current I_I, flowing through the meter winding, correspond in phase with the total current I and to keep the 90° phase difference which existed before the introduction of the thermocompensating circuit unaltered, at normal temperature, it is necessary to observe the following condition:

$$\frac{X_I}{R_I} = \frac{X_T}{R_T} = \operatorname{tg}\varphi_I . \tag{2}$$

Such a case is shown in Fig. 4. The circuit shown in Fig. 3 operates as follows. With a rising temperature, thermistor R_T decreases considerably in value. As the result of it, current I_T rises and, since the total current I remains unchanged, current I_I drops. Flux Φ_I decreases accordingly and thus compensates for the positive temperature error of the meter due to a temperature rise. Moreover the drop in the resistance R_T with rising temperature causes an increase in the ratio X_T/R_T. Thus, current I_T will no longer coincide in phase with current I, but will lag behind it by a certain angle. This means that current I_I will lead current I by angle $\Delta\psi$, i.e., the phase difference ψ between fluxes Φ_I and Φ_U will increase by $\Delta\psi$, thus, compensating for the decrease of angle ψ with temperature, which would have occurred without compensation.

Considering that the resistances R_I and reactances X_I and X_T do not depend in the first approximation either on the temperature or the current which is flowing through them it is possible to obtain the following relationship between the parameters of the thermocompensating circuit and the value of the temperature compensation it introduces.

1. The relative change in the series flux of the meter circuit produced by thermocompensation is

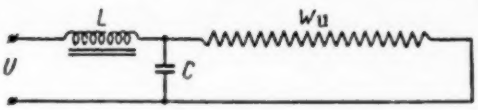

Fig. 5. Frequency-compensation circuit: W_u) parallel winding of meter; C) auxiliary capacitance; L) induction coil.

$$\delta = \frac{\alpha_T R_I}{(R_I + R_T)(1 + \mathrm{tg}^2 \varphi_I)} \Delta t, \tag{3}$$

where Δt is temperature variation;

α_T is the thermistor temperature coefficient (a negative quantity).

2. The change in the phase difference between fluxes Φ_I and Φ_U due to the thermocompensating circuit is

$$\Delta\psi = -\frac{\alpha_T R_I \,\mathrm{tg}\varphi_I}{(R_I + R_T)(1 + \mathrm{tg}^2\varphi_I)} \Delta t. \tag{4}$$

From (3) and (4) it is possible to obtain the following conditions:

$$\frac{X_I}{R_I} = \mathrm{tg}\varphi_I = -\frac{\Delta\psi}{\delta}, \tag{5}$$

i.e., in order to be able to obtain a complete compensation of the meter temperature error by means of the circuit in Fig. 3, both for the value and phase of the magnetic fluxes, it is necessary to have between the series reactance and resistance a definite ratio related to the values ($\Delta\psi$ and δ) by Eq. (5). In practice, the ratio X_I/R_I in induction meters is generally higher than that required by (5). This value is obtained by adding to the series circuit a resistance which should be made of a material with a small temperature coefficient, so as to eliminate its variation with spontaneous heating.

In the existing designs of induction electricity meters, including standard types, frequency compensation is not included. In the three-phase standard meter a circuit proposed by the author (Fig. 5) is being used.

The principle of operation of this circuit consists of the following. Variations of the mains frequency produce changes in the current flowing through choke L; thus, altering, providing the mains voltage U remains constant, the voltage across the parallel circuit of the meter and compensating for the frequency variation.

The use of the above circuit for temperature and frequency compensation led to the design of a three-phase standard meter with very small subsidiary errors. The temperature coefficient of this meter for $\cos\varphi = 1$ and $\cos\varphi = 0.5$ in the temperature range of 20 ± 10°C does not exceed 0.02% per 1°C, i.e., it is one fifth of meter V-3 temperature coefficient. Variations of frequency by ± 0.5 cps do not produce errors for $\cos\varphi = 1$ and $\cos\varphi = 0.5$ exceeding ± 0.05%, i.e., one quarter of the V-3 meter errors. Thus, the problem of measuring ac energy with an error of the order of ± 0.1% was solved.

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ERRORS IN MEASURING REACTIVE POWER BY THE TWO WATTMETER METHOD

I. N. Osher

Measurements of wattless power by means of two wattmeters as shown in Fig. 1 are based on the assumption that the zero point of the star connection lies in the vector diagram in the center of the equilateral triangle formed by the line voltages. This condition cannot be attained in practice with any accuracy, since the impedances which form the artificial zero point can always be unequal.

Let us denote the voltages across the wattmeters by U with subscripts corresponding to the numbers of the phases. Let us denote the phase voltages of a symmetrical star by U_s. Using the expression for the scalar product of vectors [1]

$$(\dot{U}\dot{I}) = UI\cos\varphi,$$

where φ is the phase difference between $\dot{U}$ and $\dot{I}$ we can write

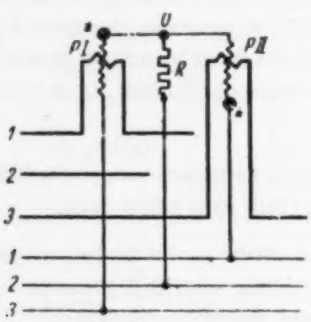

Fig. 1.

$$\Delta P = P_{\text{m}} - P_{\text{a}} = |(-\dot{U}_3 \dot{I}_1) + (\dot{U}_1 \dot{I}_3)|\sqrt{3} - |(-\dot{U}_{3s}\dot{I}_1) + (\dot{U}_{1s}\dot{I}_3)|\sqrt{3}, \quad (1)$$

where ΔP is the absolute error in measuring wattless power by means of the circuit shown in Fig. 1, due to the inequality of the impedances forming the artificial zero point.

In Fig. 2 two star connections of vector phase-voltages are shown, one with its origin at point 0 and the other at point 0'. The vectors of the first connection represent voltages across the wattmeters and of the second phase voltages of a symmetrical star, which would have been obtained if the impedances of the wattmeter parallel circuits and that of the auxiliary resistor R were equal.

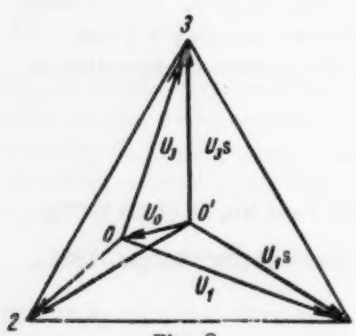

Fig. 2.

We obtain from Fig. 2

$$\dot{U}_3 = \dot{U}_{3s} - \dot{U}_0; \quad \dot{U}_1 = \dot{U}_{1s} - \dot{U}_0. \quad (2)$$

From (1) and (2) we have

$$\Delta P = |(-(\dot{U}_{3s} - \dot{U}_0))\dot{I}_1 + ((\dot{U}_{1s} - \dot{U}_0)\dot{I}_3)|\sqrt{3} - |(-\dot{U}_{3s}\dot{I}_1) + (\dot{U}_{1s}\dot{I}_3)|\sqrt{3};$$

$$\Delta P = \sqrt{3}((\dot{U}_0(\dot{I}_1 - \dot{I}_3)). \quad (3)$$

Let us find $\dot{U}_0$ for a given asymmetry of the star connection formed by the wattmeter I and II parallel circuits and the auxiliary resistor R (Fig. 1), assuming that the impedance of the phase II ray of the star (the ray of the auxiliary resistor) is equal to R, that of the phase III ray of the star (the ray of wattmeter I) to (1 + a) R and that of phase I ray of the star (the ray of wattmeter II) to (1 + b)R.

Taking the direction of $\dot{U}_{1s}$ as the real axis we have.

$$\dot{U}_0 = \frac{U_{1s}e^{-j\frac{2}{3}\pi}\dfrac{1}{R} + U_{1s}e^{-j\frac{4}{3}\pi}\dfrac{1}{(1+a)R} + U_{1s}\dfrac{1}{(1+b)R}}{\dfrac{1}{R} + \dfrac{1}{(1+a)R} + \dfrac{1}{(1+b)R}}$$

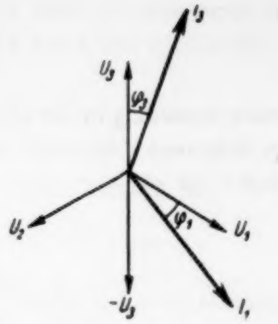

Fig. 3.

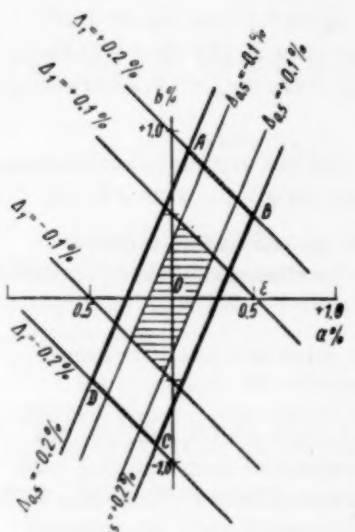

Fig. 4.

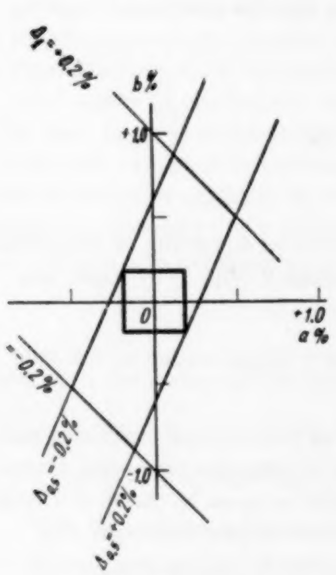

Fig. 5.

Hence after transformations we get

$$\dot{U}_0=U_{1s}\frac{a-ab-2b-j\sqrt{3}\,(a+ab)}{6+4a+4b+2ab}.$$

Neglecting the relatively small quantities we obtain

$$\dot{U}_0=\frac{U_{1s}}{6}(a-2b-j\sqrt{3}\,a). \qquad (4)$$

With a uniform load the vector difference of currents $(\dot{I}_1-\dot{I}_3)$ lags behind vector $\dot{U}_{1s}$ by $(30+\varphi)°$ and we can write from Fig. 3

$$(\dot{I}_1-\dot{I}_3)=\sqrt{3}\,I_l e^{-j(30+\varphi)°} \qquad (5)$$

The scalar product of two vectors can be obtained by taking the real part of the algebraic product of the conjugate of one by the other. Hence,

$$\Delta P=\sqrt{3}\,Re\{\overset{*}{U}_0(\dot{I}_1-\dot{I}_3)\}, \qquad (6)$$

but since

$$\overset{*}{U}_0=\frac{U_{1s}}{6}(a-2b+j\sqrt{3}\,a),$$

from (5) and the above we obtain

$$\Delta P=\frac{U_{1s}I_l}{2}Re[(a-2b+j\sqrt{3}\,a)\,e^{-j(30+\varphi)}]=$$

$$\frac{U_s I_l}{2}Re\{(a-2b+j\sqrt{3}\,a)[\cos(30+\varphi)-j\sin(30+\varphi)]\}=$$

$$=\frac{U_{1c}I_l}{2}[(a-2b)\cos(30+\varphi)+\sqrt{3}\,a\sin(30+\varphi)]=$$

$$\frac{U_{1s}I_l}{2}[(1.866a-2b)\cos\varphi+(a+b)\sin\varphi]. \qquad (7)$$

Considering that the actual value of the wattless power is expressed by the formula

$$P_a=3U_p I_l\sin\varphi, \qquad (8)$$

where $U_p=U_{1s}$, we have

$$\frac{\Delta P}{P_a}=\frac{1}{6\sin\varphi}[(1.866a-2b)\cos\varphi+(a+b)\sin\varphi]=$$

$$=\frac{1.866a-2b}{6}\text{ctg}\varphi+\frac{a+b}{6}.$$

If a and b are given in percentages, the error of measuring wattless power according to the circuit shown in Fig. 1 and due to the inequality of the resistances forming the artificial zero circuit can be expressed in percentages as well:

$$\Delta=\frac{\Delta P}{P_a}100\%=(0.311a-0.333b)\text{ctg}\varphi+0.167(a+b). \qquad (9)$$

Since a and b do not normally exceed 0.5% it is possible to simplify

the formula and write finally

$$\Delta=[0.2(a+b)+0.3(a-b)\operatorname{ctg}\varphi]\,\%. \tag{10}$$

Formula (10) provides the relation between the error of measuring wattless power according to the circuit in Fig. 1 and the deviation of the resistances of the wattmeter parallel circuits from resistance R expressed in percentages and for any phase angle φ. For the particular cases of $\sin\varphi = 1$ and $\sin\varphi = 0.5$ we have

$$\Delta_1=0.2\,(a+b)\,\%, \tag{11}$$

$$\Delta_{0.5}=(0.7a-0.3b)\,\%. \tag{12}$$

In order to be able to determine the permissible values of a and b from tolerances $\pm|\Delta_1|$ and $\pm\,|\Delta_{0.5}|$ Eqs. (11) and (12) can be represented graphically as two families of curves b = f(a) (for $\sin\varphi = 1$ and $\sin\varphi = 0.5$) plotted for different values of Δ_1 and $\Delta_{0.5}$ (Fig. 4).

It will be easily seen that the coordinates of the points lying between lines $\Delta_1 = +0.1\%$ and $\Delta_1 = -0.1\%$ are equal to the values of a and b which provide an error of wattless power measurement Δ_1 (for $\sin\varphi = 1$) does not exceed $\pm$ 0.1%. The coordinates of the points lying between lines $\Delta_{0.5} = +0.1\%$ and $\Delta_{0.5} = -0.1\%$ are equal to values of a and b for which $\Delta_{0.5}$ (at $\sin\varphi = 0.5$) does not exceed $\pm$ 0.1%.

The points within the shaded parallelogram provide values of a and b for which the wattless power measurement error due to the asymmetry of phase voltages does not exceed $\pm$ 0.1% both for $\sin\varphi = 1$ and $\sin\varphi = 0.5$.

The parallelogram ABCD within which lie the points whose coordinates give the permissible values of a and b for the given error of power measurement of $\Delta = \pm$ 0.2% we shall call the parallelogram of the permissible $\pm$ 0.2% error.

There is a definite parallelogram in Fig. 4 corresponding to any permissible value of a power measurement error.

Point B lies in the $\pm$ 0.2% error parallelogram and its coordinates are a = 0.5 and b = 0.5%, i.e., for this error of measurement the permissible deviation of the wattmeter parallel circuit resistances from resistor R must be 0.5%. This does not mean, however, that with deviations of the wattmeter resistances from R of less than 0.5% the error will not exceed 0.2%. Point E lies outside the limits of the $\pm$ 0.2% error parallelogram although its coordinates do not exceed 0.5; thus with a and b less than 0.5 the error of measurement is greater than 0.2%.

In what field of tolerance should a and b be for a given error of measurement $\Delta_1 = \Delta_{0.5} = \Delta$? The answer to this question can be found from (11) and (12) in the following manner. Let us find the maximum value for Δ_1 and $\Delta_{0.5}$ with $|a| = |b|$.

We then have

$$\Delta_1\max = 0.2(|a|+|b|)\,\% = 0.4|a|\,\%;$$

$$\Delta_{0.5}\max=(0.7|a|+0.3|a|)\,\% = |a|\,\%.$$

This brings us to the conclusion that for the error of wattless power measurements according to this method (Fig. 1) not to exceed $\pm$ d%, the wattmeter resistances must not deviate from resistor R (Fig. 1) by more than $\pm$ d%, but these deviations can have the same or opposite signs.

The points whose coordinates correspond to the latter conclusion lie within a square resting on the error parallelogram (Fig. 5).

Instruction 195-54 for checking power and wattless power electricity meters recommends for testing three conductor induction meters to connect two wattmeters across the phase voltages by using the zero point formed in a three-phase installation by phase regulators or transformers. It would be more accurate to obtain this point by means of the circuit shown in Fig. 1, since in testing equipment large differences in phase voltages may occur due to inequalities in the windings forming the zero point. This has been rectified in the new issue of instruction 195-54, where the deviations of the wattmeter parallel circuits from each other are specified, however, if grade 0.5 wattmeters are used whose parallel circuit resistance can deviate from the nominal value by

0.5% it should be considered that a = + 0.5% and b = − 0.5%. These values of a and b correspond in Fig. 4 to point F which lies outside the $\Delta_{0.5} = \pm\ 0.2\%$ region. The value of the error $\Delta_{0.5}$ can be found in this case from (12):

$$\Delta_{0,5}=0,7\cdot 0,5+0,3\cdot 0,5=0,5\%.$$

It will be seen that the error is quite substantial.

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BALANCING TO GROUND HIGH-TENSION AC BRIDGES

N. V. Levitskaya

Several types of high-tension precision ac bridges which provide measurements of small loss angles (of the order of 10^{-4}) are produced with a set of auxiliary equipment for balancing out the reactances of the low-voltage bridge arms Z_3 and Z_4. Among the Soviet bridges the MDP and the "Tochélektropribor" P525 bridges belong to this category.

Let us analyze the schematic of these bridges by taking as an example the latest one of their kind, bridge P525 (see figure). The circuit is shown for high-voltage measurements; dotted lines represent the component connected to the bridge separately.

Bridge P525 similar to other bridges of this type is designed on the basis of a modified Schering bridge [1]. The bridge circuit eliminates, as it will be demonstrated later, to a sufficient extent, the effect of stray leakages and capacities on the results of the measurements. This circumstance raises the accuracy of the bridge especially when measuring small loss angles.

The standard capacitor C_0 of a three-terminal type is connected to the bridge externally. This eliminates the effect produced on balancing by the stray capacities and leakages between the high-tension electrode and the grounded body of the capacitor. The effect of the capacity between the low-voltage electrode and the grounded screen (including the capacity of the connecting screened cable) is eliminated by raising the potential of the zero diagonal of the bridge to that of the screen. For this purpose an additional voltage controlled both in phase and magnitude is introduced between the bridge point D and ground (screen). This voltage is obtained at the output of an auxiliary equipment built into the bridge. The screening of the R525 bridge is effective and provides the possibility of measuring small loss angles with the required accuracy. In measuring small loss angles, however, it is also necessary to take into account the initial capacity of the standard box of capacitors C_4. Here

$$\operatorname{tg}\delta_x=\omega R_4(C_4-C_1) \tag{1}$$

where δ_x is the measured loss angle;

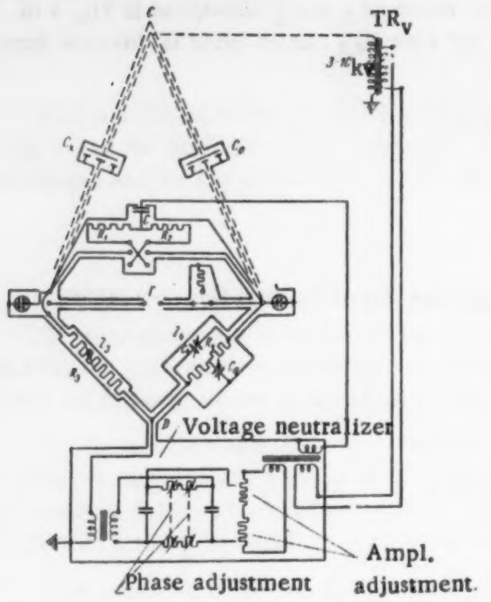
R_4 is the resistance of arm Z_4;

C_1 is the initial capacity of the box of capacitors C_4;

ω is the operating frequency.

In a normal Schering bridge circuit it is impossible to measure tg δ smaller than $\omega R_4 C_1$.

In the bridges under consideration the compensation of the initial capacity of the standard box of capacitors is attained by connecting between the midpoint of resistor R_4 and the screen a capacity C_a. For $C_a = 4C_1$ the initial capacity of the box of capacitors will not affect the measuring results.



In all the bridges of this type the required relation between C_a and C_i is obtained by means of balancing the reactances of the low-voltage arms Z_3 and Z_4 in an equal arms bridge circuit, by means of so-called symmetrization operation. In this operation the Z_4 arm is compensated for the initial capacity of the C_4 capacitor box and the time constants of resistors R_3 and R_4 are equalized.

When the circuit is being initially balanced the low-voltage arms are connected to two equal nonreactive resistors R_1 and R_2 instead of the standard and unknown capacitors. In order to make the potential distribution in the low-voltage arms of the bridge with respect to the screen the same as in normal working, the voltage is supplied to the balancing circuit through a phase-shifting capacitor C. The balancing circuit is supplied either through a special transformer (as in the Leeds and Northrup and MDP bridges) or as in the R525 bridge through an additional winding of transformer T, which feeds the auxiliary circuit. Capacitor C_a uniformly graduated scale is mounted on the face panel of the bridge.

The bridges are symmetrized before every run of measurements. For this purpose a balancing equipment consisting of two nonreactive resistors a phase-shifting capacitor C and a supply transformer are connected to the MDP bridge. Above equipment is incorporated in the P525 bridge.

Experience in checking the high-tension bridges MDP and P525 at All-Union Scientific Research Institute of the Committee of Standards, Measures and Measuring Instruments and several other organizations, including the Moscow transformer plant, shows that the values of C_a once set by balancing retains for a considerable time the bridge balance which is practically not affected by external factors. The analysis of the MDP and R525 bridge circuits confirms that the reactances of the low-voltage bridge arms are sufficiently stable with time and depend but little on the external conditions. In fact the residual capacity of the capacitor box C_4 in practice amounts to some 50-100 $\mu\mu f$. The variations of the residual capacity of the box do not exceed 5% during a long time and only rarely amount to 10-15%. The same applies to the stability of the residual capacity of boxes mass-produced by our industry.

Hence the loss angle error due to the variations ΔC_i of the initial capacity of the standard capacity box will not exceed according to formula (1)

$$\Delta \mathrm{tg}\delta = \omega R_4 \Delta C_i \tag{2}$$

In the worst case this error amounts to $(1\text{-}2)\cdot 10^{-5}$, i.e., is small compared with the error permissible for these bridges ($\pm\ 6\cdot 10^{-5}$). The time constants of resistors R_3 and R_4 are also constant with time and practically independent of external factors. Symmetrizations provides a balance of the low-voltage arms Z_3 and Z_4 reactance due to the induction of resistors R_3 and R_4 only if the above resistors are equal. In all other cases the equalization of the time constants no longer holds since R_3 varies over a wide range. In order to make the effect of the time constants small for all the conditions the bridge may be used under, above resistors are made nonreactive, i.e., with sufficiently small time constants.

From the above it becomes obvious that, with modern production methods, symmetrization of the precision high-tension bridges need only be made when they leave the factory and following an overhaul instead of carrying it out before every series of measurements as it is prescribed by the instructions. This would speed up considerably all the measurements, since symmetrization is a labor-consuming process, especially with the MDP bridges whose balancing circuit has not been designed successfully.

The possibility of symmetrizing bridges only once would simplify their construction both owing to a decrease in the number of adjusting elements taken out at the face panel and other control units and elements. There is no necessity to use a variable air capacitor for balancing. It can be replaced by a mica or plastic film

hermetically sealed capacitor with a small trimming capacitor in parallel. The stability of these capacitors is high, amounting to hundredths of one percent, and the temperature coefficient is known to be smaller than 0.1% per 10°C. Thus, the possible variation of the capacity $C_a = 4C_1$ owing to all the possible factors, including the changes in the capacity of the trimmer, will not exceed under the operating conditions of the bridges MDP and R525, a few hundredths of one percent. The error in the loss angle measurement will not exceed a few parts in 10^{-6}, which is a small quantity compared with the permissible error of measurement of the bridge. The loss angle of the capacitor with the proposed change will remain smaller than 10^{-3}, thus, producing an error in the capacity measurement not exceeding hundredths of one percent.

The auxiliary equipment used for symmetrization will only be required by the manufacturing plants and the repair organizations.

Above measures will simplify the construction of high-tension bridges, and the technology of their production, reduce their cost and make them easier to operate.

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SENSITIVITY OF UNBALANCED BRIDGE CIRCUITS

M. A. Kaganov

The best parameters for power sensitivity of an unbalanced four-arm dc bridge [1] are considered to be those which provide a maximum value for ratio P_0/P_1. Here P_0 is the power received by the galvanometer and P_1 the power dissipated by the source of supply at a given (maximum) unbalance of the bridge.

This conclusion ignores the fact, analyzed in detail in [2], that the maximum power dissipated by the source may occur at a value of the source resistance which is not extreme but falls within the measuring range. Thus, the recommendations given in [1] are not applicable to a general case. The method of evaluating the sensitivity of unbalanced bridges suggested by us previously [2], based on the value of ratio P_0^x/P_1^x, (where P_0^x is the power fed to the measuring instrument when it is fully deflected, and P_1^x is the maximum value of the power dissipated by the source in the measuring range) is a more general criterion for selection of optimum bridge parameters.

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A TRANSISTOR INSTRUMENT FOR DETERMINING THE SUSCEPTIBILITY OF ROCKS

Ya. E. Gruns and E. A. Suvorov

This instrument* is designed to measure magnetic susceptibility χ of rock specimens and metallometric samples in field conditions. Specimens with at least one flat surface are suitable for measurements. Besides using samples, measurements can be made directly on outcroppings.

The schematic circuit of the instrument is shown in Fig. 1 (the part enclosed by a dotted line represents the position of the switch for checking the supply).

The principle of the operation of the set consists of the following.

A differential circuit consisting of two choke coils supplied by an ac generator is balanced in air. When a sample is brought close to the set the inductance of one of the choke coils changes. This produces at the output of the differential circuit an unbalanced voltage which is fed to an amplifier, is rectified, and measured by a moving-coil microammeter. It should be noted that a possible unbalance of the differential circuit due to conductance of the rocks does not occur in this instrument.

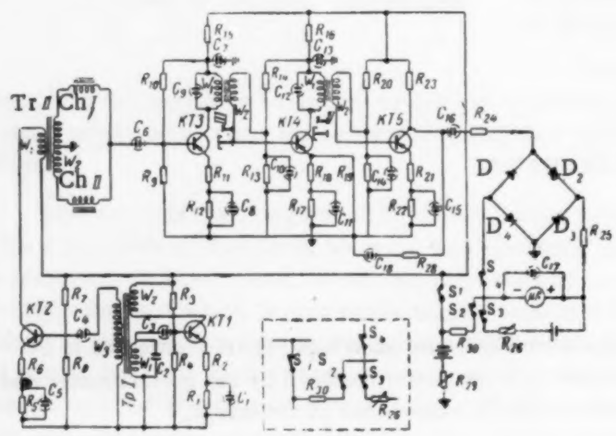

Fig. 1.

Circuit components. The transducer (in Fig. 1, Ch 1) consists of a choke coil which has a ferromagnetic (permalloy) E-type core with an air gap. The other arm of the differential circuit is similarly constructed. Both coils are enclosed in a double vinyl plastic beaker and are connected to the instrument by a three-core flexible cable (Fig. 2).

Accurate balancing is attained by approaching a permalloy plate to the core of the second coil. The distance between the plate and core is controlled by means of a micrometer screw.

Magnetic susceptibility is calibrated in the range of 10^{-2} CGSμ against known samples by controlling the gain of the amplifier with resistor R_{23} in the feedback circuit. For measurements in the range up to 0.2 CGSμ the scale is calibrated by adjusting the gap between known sample and the transducer. The required gap is set by moving the external container and fixed by means of the holding screw.

For the convenience of varying the limits of measurements, calibration, and reading, it is desirable to have a linear scale. This can be achieved, providing the relation between the voltage at the output of the differential circuit and magnetic susceptibility χ of samples is linear (the amplifier and rectifier are linear in the operating range). The evaluation of the transducer linearity can be carried out in the following manner.

The inductance of a turn with current I placed at the boundary of two media with permeabilities μ_1 and μ_2 is expressed by equation:

$$L = \frac{\Phi}{I}, \tag{1}$$

and the flux by

$$\Phi = \frac{KI}{R_{\mu_1} + R_{\mu_2}}. \tag{2}$$

*K. Khaliulina, student at the Ural Polytechnical Institute, participated in the development of the instrument.

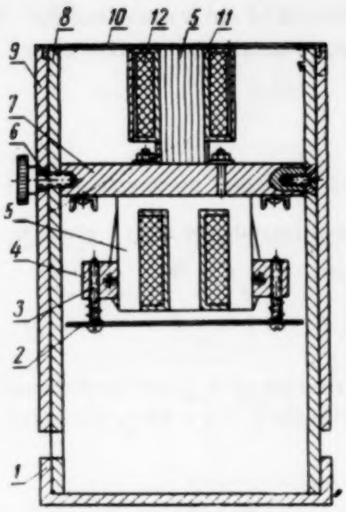

Fig. 2. Construction of the transducer: 1) Bottom cover; 2) adjusting plate; 3) micrometer screw; 4) spring holder; 5) permalloy core; 6) holding screw; 7) coil mounting panel; 8) internal container; 9) external container; 10) top cover; 11) core; 12) winding.

where $R_{\mu 1}$ and $R_{\mu 2}$ are the reluctances of the first and second media;

K is a coefficient depending on the choice of units.

From the condition that the turn is at the boundary of two media it follows that

$$\left.\begin{aligned} R_{\mu_1} &= \frac{l}{\mu_1 S}, \\ R_{\mu_2} &= \frac{l}{\mu_2 S}, \end{aligned}\right\} \tag{3}$$

where l is half the length of a magnetic line of force;

S is the cross section at the boundary of the media.

Substituting (2) and (3) in (1) we have:

$$L = \frac{P\mu_1\,\mu_2}{\mu_1+\mu_2}, \tag{4}$$

where

$$P = \frac{KS}{l}.$$

From (4) we obtain for $\mu_1 \gg \mu_2$:

$$L \simeq P\mu_2. \tag{5}$$

It follows from the above that in devices measuring magnetic susceptibility the scale will only be linear if the permeability of the device is much higher than that of the medium under test.

In practice this means that the core of the transducer must be made of permalloy or ferrites with permeability of the order of several thousands of CGSμ units.

With large values of μ the set can be calibrated by adjusting the distance between transducer and sample. The scale will remain linear providing

$$R_{\mu_1} + R_{\mu\ \mathrm{gap}} \ll R_{\mu_2}.$$

The value of P in expression (5) is determined experimentally by means of a sample with a known magnetic susceptibility.

The voltage U_0 at the output of the differential circuit can be found from the equivalent circuit of transducer Z_1 (Fig. 3)

By making up current equations and solving them with respect to $U_0 = I_0 Z_0$ we find:

$$2U_0 = I_1 Z_1 - I_2 Z_2. \tag{6}$$

Assuming that $I_1 = I_2 = I \gg I_0$, we have

$$U_0 = U\,\frac{Z_1 - Z_2}{Z_1 + Z_2}. \tag{7}$$

It will be seen from (7) that the relation between U_0 and Z_1 is nonlinear. By setting a certain measurement tolerance, however, this nonlinearity can be neglected.

In order to establish the permissible variation of the transducer impedance Z_1, for a given error of measurement let us use the following method. By drawing a tangent to curve representing expression (7) at point $Z_1 = Z_2$,

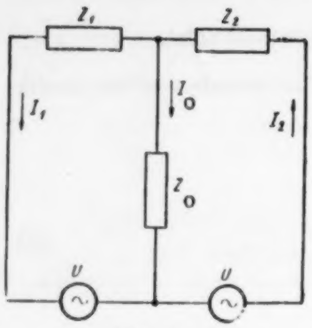

Fig. 3.

and dividing the difference between the ordinates of the tangent and the curve by the value of the curve at that point, we obtain the relative error in the form

$$m = \frac{Z_1 - Z_2}{2Z_2}. \tag{8}$$

Then the maximum variation of the transducer impedance with a given m will be determined from equation

$$(Z_1 - Z_2)\max = \Delta Z \max = m 2Z_2. \tag{9}$$

In this transducer $\omega L \gg R$ and the variation of Z_{ch} are proportional to those of L, and hence according to (5), and since $\mu = 1 + 4\pi\chi$, the maximum value of χ, measured with the permissible error m, is equal to

$$\chi_{max} = \frac{m}{2\pi}. \tag{10}$$

The generator consists of two stages: the oscillator and the power amplifier working with KT_1 and KT_2 transistors. The oscillator is of the base tuned, transformer, coupled type. Both stages are thermostabilized by a negative feedback established by means of three resistances [1], which are respectively R_1, R_3, R_4 and R_5, R_7, R_8.

The output voltage of the generator is 3 v and the frequency 965 cps.

From the differential circuit the voltage is fed to the first stage of the amplifier, consisting of transistor KT_3. The stage has a large current feedback and has a high input impedance. A tuned circuit is connected in series with the collector and coupled inductively to the next stage which is also tuned. The use of a tuned amplifier discriminates against the harmonics produced at the output of the differential circuit. In addition this provides the means of perfect matching of the stages, thus reducing the number of transistors required and obtaining better temperature stability. All the amplifier stages are thermostabilized similarly to the oscillator stages. It should be noted that for a good gain stability with changing temperature the collector current in each stage should be fixed at not less than 1 ma.

The amplified signal is rectified in a conventional bridge rectifier. The circuit is thermostabilized by means of two resistors R_{24} and R_{25} which are selected experimentally for a given temperature range.

The zero is set initially by means of a variable resistor R_{26} connected to a separate battery.

The sensitivity of the instrument is 10^{-5} CGSμ, its accuracy in the temperature range of − 40 to + 60°C is ± 10%, and its range is 10^{-5} to 0.2 CGSμ.

The instrument is fed from three KBS-L-0.5 batteries. One set of batteries lasts 100 hours.

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A SET FOR CHECKING FREQUENCY METERS

A. I. Kuz'min

Many State Inspection Laboratories do not check industrial frequency meters both of the vibration and indicating pointer types, thus incurring additional expenditure in sending them to other State Inspection Laboratories; moreover some of the generators remain for a short time without frequency meters.

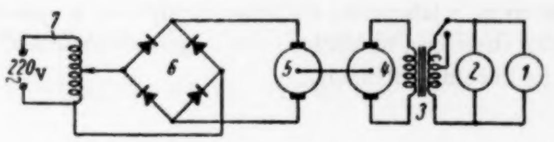

Fig. 1.

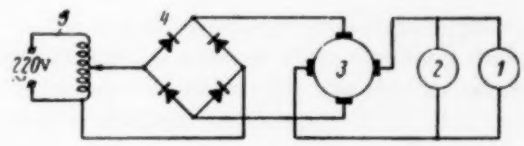

Fig. 2.

The author proposes a test circuit (two versions, according to the available equipment) which was successfully used at the Mogilev State Inspection Laboratory.

The circuit is simple and the device reliable in operation. It can be made at any State Inspection Laboratory or a permanent branch without outside assistance; moreover, all the equipment used in the device can be obtained on the spot.

First version. (Fig. 1). The frequency meter under test 1 and the standard one 2 are connected in parallel to an 80 w, 6/220/110 v step-up transformer 3, which in turn is connected to an ac generator 4 type G-31, 60 w, 6 v (from the "Belarus" tractor). The generator is driven by a dc motor 5, in our case an automobile dynamo type GBF-4105. The ratio of the pulley diameters of the motor and generator were 2:1.

The motor is connected to the 220 v line through a selenium rectifier 6 type VSA-5, 64 v, 12 amp. The speed of the motor is controlled by means of the autotransformer 7 type LATR-2, thus changing the generator frequency in the range of 45-55 cps.

Second version. (Fig. 2). The frequency meter under test 1 and the standard one 2 are connected in parallel to a motor-generator (converter) 3, of 70 w, 220/220 v, 3000 rpm, and 50 cps. The motor-generator is connected to the line through a selenium rectifier 4 type VSA-4. The speed of the motor and hence the frequency of the generator is controlled by means of the autotransformer 5 type LATR-2.

A PORTABLE SET FOR CHECKING AC AMMETERS AND VOLTMETERS

S. G. Shepelin

The checking of rack-mounted electrical instruments is usually carried out on stationary test installations. For this purpose it is necessary to dismount the instruments from the boards and deliver them to the laboratories, thus involving skilled mechanics in a considerable amount of work.

V. A. Vorontsov, an industrial laboratory electrician, developed a portable installation by means of which instruments can be checked on the spot without dismantling them.

The equipment weighs 20 kg, is mounted in a case and includes the following instruments: an ammeter type AST with a range of 2.5-5 amp; a voltmeter type ASTV with a range of 150-300 v; multiplying resistors

type DV for extending the range to 450 and 600 v; current transformer UTT-5 with primary currents of 15, 50, 100, 150, 200, 300,and 600 amp and a secondary current of 5 amp; a laboratory autotransformer type LATR-2; a load transformer with a 220 v primary, secondary voltage 450-500 v, step-down windings of 3 v at 5 amp and 6-8 v at 50 amp.

By means of this equipment it is possible to check ammeters up to 50 amp and voltmeters up to 450 v.

Its use resulted in a saving to the factory of 7000 rubles .

Editorial note. The checking of ammeters and voltmeters on a laboratory stationary equipment is speedier than on the above device. The question of its adoption should, therefore, be decided with regard to particular conditions which may make the dismounting of instruments for checking difficult.

MEASUREMENTS AT HIGH AND ULTRAHIGH FREQUENCIES

APPLICATION OF THE PHASE DETECTOR FOR MEASURING WEAK SIGNALS

V. S. Voyutskii

For measuring weak periodic signals (phase otherwise known as synchronous) detectors are widely used. The schematic of a simple phase detector is shown in Fig. 1. It represents a six-terminal network with two inputs to which two independent voltages are fed, and one output which supplies a voltage (current) proportional to the product of the input variables.

The process of phase (synchronous) demodulation is in essence a correlation process and thus the phase detector, with an RC network connected in series with it, can be considered as a correlation element.

A correlation element performs two operations; it produces the product of two* voltages

$$Z = U_1(t)\, U_2(t+\tau) \tag{1}$$

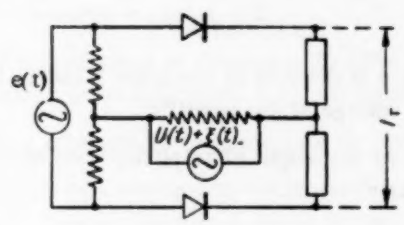

Fig. 1.

and averages the product over time T determined by time constant RC

$$Z_T = \frac{1}{T}\int_0^T Z\,dt. \tag{2}$$

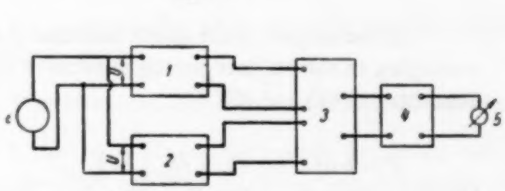

Fig. 2.

Measurement of periodic signals. The phase detection method can be used when the frequency ω_0 of the signal is known. The phase detector is fed, in addition to the signal U (t) and interference ξ (t), with a periodic signal e (t) of frequency ω_0. We shall obtain at the output:

$$I_T(\tau) = \frac{1}{T}\int_0^T [U(t)+\xi(t)]e(t+\tau)dt = B_{ueT}(\tau) + B_{\xi eT}(\tau). \tag{3}$$

Here $B_{ueT}(\tau)$ is the transient mutual correlation function of signals U (t) and e (t).

$B_{\xi eT}(\tau)$ is the transient mutual correlation function of signal e (t) and the interference.

For $U(t) = A_1 \cos \omega_0 t$ and $e(t) = A_2 \cos \omega_0 (t+\tau)$ we have

$$B_{ueT}(\tau) = \frac{A_1 A_2}{2} \cos \omega_0 \tau \tag{4}$$

and

$$B_{\xi eT}(\tau) \to 0. \tag{5}$$

*We are considering a two-channel correlation element.

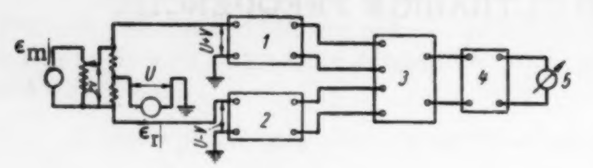

Fig. 3.

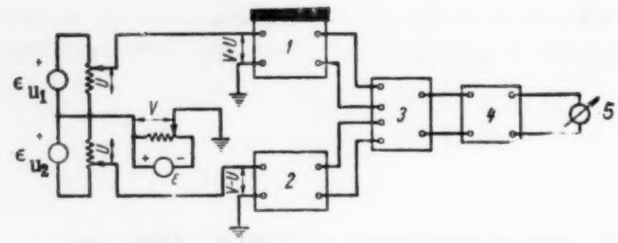

Fig. 4.

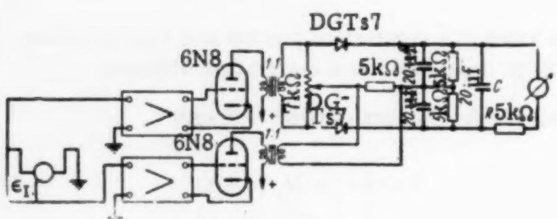

Fig. 5.

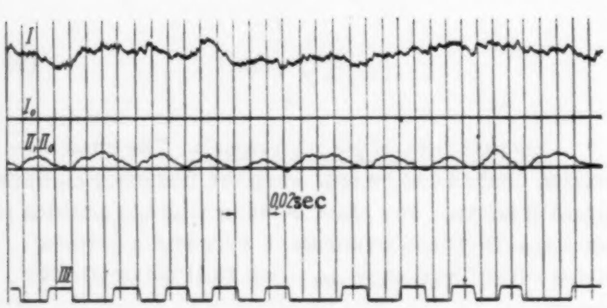

Fig. 6.

For $\tau = 0$

$$B_{ueT}(0) = \frac{A_1 A_2}{2}. \tag{6}$$

It follows from the above that the mean value of the voltage at the output of the detector is, with a sufficiently long time T, independent of the intensity of interference.*

Measurement of signals with a continuous spectrum. Phase detectors are also used for measuring weak signals with a continuous spectrum [2, 3, 4].

Let us examine measuring circuits developed by the author which do not require modulating devices [5].

Figure 2 shows a block schematic for measuring signals with a continuous spectrum. Voltage U (t) is fed in phase from the generator of the measured signals to the inputs of similar amplifiers 1 and 2. At the output of amplifier 1 we have the voltage

$$\alpha\,[U(t)+\xi_1(t)],$$

where α is the gain of amplifier 1 and ξ_1 is the noise voltage of the amplifier.

At the output of amplifier 2 we have similarly

$$\beta\,[U(t)+\xi_2(t)].$$

At the output of the phase detector 3 after averaging in the RC integrating network 4 we have according to (1) and (2)

$$Z = k\alpha\beta(\overline{U^2}+\overline{U\xi_1}+\overline{U\xi_2}+\overline{\xi_1\xi_2}) = k\alpha\beta\,[B_{uuT}(0)+B_{u\xi_1T}(0)+B_{u\xi_2T}(0)+B_{\xi_1\xi_2T}(0)], \tag{7}$$

where k is a certain coefficient depending in the main on the parameters of the equipment;

$B_{uuT}(0)$ is the transient autocorrelation function of the measured signal for $\tau = 0$.

$B_{u\xi_1T}(0)$, $B_{u\xi_2T}(0)$, $B_{\xi_1\xi_2T}(0)$ are transient mutual correlation functions of signals and noise for $\tau = 0$.

$B_{u\xi_1T}(0)$ and $B_{u\xi_2T}(0)$ are equal to zero since the useful signal and noise are statistically independent. The noise mutual correlation function $B_{\xi_1\xi_2T}(0)$ decreases with a rising time constant RC and tends to zero. There remains the useful signal correlation function whose mean value is not equal to zero.

Thus, indicator 5 at the output of the circuit only records the useful signal:

$$Z = k\alpha\beta\overline{U^2}. \tag{8}$$

Figure 3 shows a block schematic** for measuring by the null method, which is used, for instance, in comparing

*For quantitative calculation of noiseproof correlation reception of signals see [1].

**The numbering in Figs. 3 and 4 is the same as in Fig. 2.

the measured signal with a reference one [6]. Here ϵ_m and ϵ_r are generators of the measured and reference signals.

Voltage U of the measured signals is fed in phase to the inputs 1 and 2; voltage V of the reference signal in antiphase.

At the output of amplifier 1 we have voltage $\alpha[U(t) + V(t) \cdot \xi_1(t)]$, and at the output of amplifier 2 we have similarly

$$\beta[U(t) - V(t) + \xi_2(t)].$$

At the output of the phase detector 3, after averaging by means of the RC network and neglecting the mutual correlation function of the signal and noise and the mutual correlation function of the noise of both amplifiers, we obtain:

$$Z = k\alpha\beta[B_{uuT}(0) - B_{vvT}(0)] = k\alpha\beta(\bar{U}^2 - \bar{V}^2). \tag{9}$$

When the measured and the reference voltages are equal (U = V), $\bar{U}^2 = \bar{V}^2$ and Z = 0, i.e., when the measuring is done by the null method, the instability of gain does not produce errors of measurement.

In addition to the amplifier noise the noise of the sources of signals (photoelements, photoelectric multipliers, particle counters, bolometers, etc.) play an important role.

In certain cases the main interference is caused by noises arriving from the external medium.

Figure 4 shows a block schematic of a circuit for eliminating not only noises of amplifiers but also those of the signal sources and the external media [7]. Here ϵ_{u1} and ϵ_{u2} are two generators of signals, for instance, antennas, particle counters, etc.

If it is required to eliminate the effect of the of noises of amplifier and generator,the latter need not be at a distance from each other but their signals must be coherent.

The antennas,for instance,must be identical and the counters connected in a coincidence circuit.

If it is also required to eliminate the effect of external noise, the two identical generators are placed at a definite distance from each other, in such a manner that the distance between them and their orientation in space provide coherent signals, but make external noise statistically independent.

An example of a phase detector circuit. Figure 5 shows a circuit used for detecting very weak acoustic and seismic signals.

Two identical amplifiers with a frequency band of 50 to $5 \cdot 10^3$ cps and high gain were used.

It should be noted that a wide frequency band provides an identical phase shift in amplifiers; when wide-band amplifiers are used for these measurements no phase correction is required.

For matching the amplifier outputs with the input of the phase detector,identical transformers with a turns ratio of 1 : 1 were used. The time constant of the integrating circuit varied between 0.1 and 1.0 sec.

A microammeter type M-95 with graduations of 10^{-7} to 10^{-8} amp was used as an output instrument; an oscillograph loop was also connected to the output. Figure 6 shows oscillograms which illustrate the noiseproofing of the circuits described above: oscillogram I was received with a conventional* measuring circuit, I_0 being the corresponding zero line. Audio frequency signals were fed to the input (U = 0.25 to 0.5 μv) on a background of equipment noise which considerably exceeded them in amplitude (the mean voltage of the noise was about 10 μv).

Oscillogram II of the same signal on the background of the same noise** was obtained with a phase detector

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*We consider a conventional circuit as consisting of an amplifier, square law detector, and a measuring instrument. The instrument measures the direct component of the detector current, which depends both on the intensity of the measured signal and that of the equipment noise.

**The square-law detector of the conventional measuring circuit was fed from the output of the phase detector amplifiers, for which purpose the amplifier output transformers had an additional secondary winding; thus both circuits recorded simultaneously the same signal on the background of the same equipment noise.

(the time constant RC = 0.1 sec):II_0 is the corresponding zero line. The signals were fed to the line in the intervals of curve III pulses.

The advantages of the circuit with a phase detector are obvious, since the latter clearly responds to each signal, whereas separation of signals on oscillogram I is impossible.

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A SYSTEM FOR COMPARING THE FREQUENCY OF A MOLECULAR GENERATOR WITH A CRYSTAL STANDARD

A. Ya. Leikin

For systematic comparison of a molecular generator frequency with that of a highly stable crystal oscillator used as a frequency standard, the Khar'kov State Institute of Measures and Measuring Instruments (KhGIMIP) developed and constructed a special apparatus.

The frequency of the Khar'kov Institute quartz crystal standard was 60 kc. Raising it to the frequency of the molecular generator (23170 Mc) involves a very large multiplication factor with the multiplication beginning at very low frequencies. Under these conditions it is difficult to obtain a pure monochromatic signal at the output of the multipliers. In this connection an auxiliary crystal oscillator of 3.1 Mc was used. Figure 1 shows the block schematic of the first version of the device. Its principle of operation consists in the following. The 3.1 Mc signal of the crystal oscillator after multiplication ($n_1 n_z$ = 7700 times) is mixed with the signal of the molecular generator. The signal of the difference frequency ($F_2 = f_c n_1 n_2 - f_m$) is amplified and fed to the first computer. A part of the (n_1 = 11 times) multiplier output power is fed to a mixer which is also fed the standard frequency multiplied n_3 = 374 times. The thus obtained difference frequency ($F_1 = f_c n_1 - n_3 f_s$) is amplified and fed to the second computer. From the readings of the computers the relation between the quartz standard frequency f_s and that of the molecular generator f_m can be determined

$$f_s = \frac{f_m + F_2 - 700F_1}{238700} \tag{1}$$

(and, vice versa, f_m from f_s).

Here f_s is the quartz standard frequency converted to 100 kc;

f_m is the frequency of the molecular generator;

F_1 and F_2 are readings of the two computers.

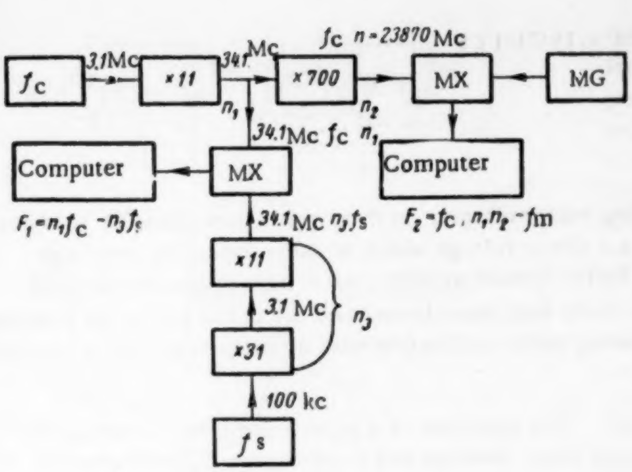

Fig. 1.

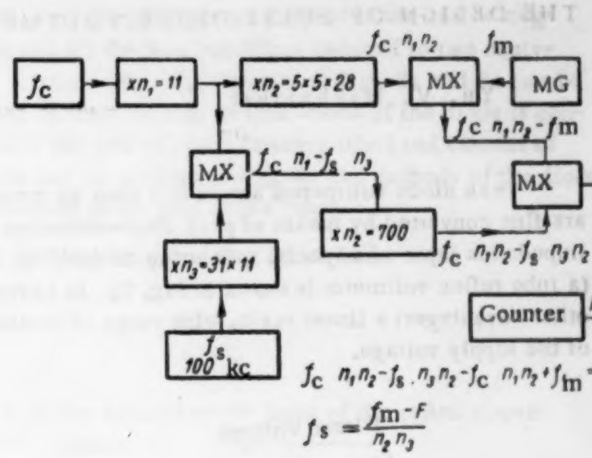

Fig. 2.

№.	F_1, cps	F_2, cps	f_m, Mc
1	18.10	600	23870.12730
2	18.10	600	23870.12730
3	18 10	610	23870.12731
4	18.10	600	23870.12730
5	18.11	560	23870.12733
6	18.11	570	23870.12734
7	18.11	570	23870.12734
8	18.11	580	23870.12735
9	18.10	600	23870.12730
10	18.10	600	23870.12730

Moreover, if the starting and stopping of the two computers is made simultaneously, the instability of the auxiliary crystal oscillator is eliminated, and does not affect the accuracy of measurements. The time of counting is determined by the required accuracy of the frequency measurement. With the count time, the accuracy increases with the rise in the count frequency. Hence if the count time of the difference frequency $F_1 = n_1 f_c - f_s n_3$ satisfies the required degree of accuracy, frequency $F_2 = n_1 n_2 f_c - f_m$ will automatically satisfy this condition. Thus, if the count duration is taken as t = 100 sec, the error in comparing the crystal generator with the standard at a frequency of 34.1 Mc will be $\sim 3 \cdot 10^{-10}$ and at the frequency of comparison of the crystal oscillator with the molecular generator (23870 Mc) it will be $\sim 4 \cdot 10^{-13}$.

By means of this comparison system the Khar'kov Institute regularly compares the frequencies of the molecular generator and the quartz crystal standard. The table shows the results obtained in a series of measurements with a constant tuning of the molecular generator. The frequency of the standard is taken to be 100 kc (in fact, the frequency of the 3rd standard generator of the Khar'kov Institute with which the measurements were made is a little higher than the nominal value, and in order to obtain the actual value of the molecular generator frequency a correction should be made).

It follows from the table that the mean square error of a number of frequency measurements amounts to $\sim 1 \cdot 10^{-10}$. This includes, however, the instability of the quartz standard generator which is of the same order. In order to simplify the measuring procedure and automatically exclude the instability of the auxiliary crystal oscillator, a second version of the circuit was developed, whose block schematic is shown in Fig. 2. This circuit differs from the first one by having instead of computer F_1, a frequency multiplier with a factor of $n_2 = 700$ and a mixer, in whose output a signal of frequency F is obtained:

$$F = f_c\, n_1 n_2 - f_m\, n_2 n_3 - f_c\, n_1 n_2 + f_m$$

The frequency of the crystal standard is determined by that of the molecular generator (or, vice versa, f_m by f_s) and the reading of the counter:

$$f_s = \frac{f_m - F}{238700}. \qquad (2)$$

In this work, assistance was rendered by L. V. Baulin, who made and tested the auxiliary crystal oscillator, and E. Z. Orlov, who participated in the production and testing of the entire comparison system.

THE DESIGN OF PULSE DIODE VOLTMETER CIRCUITS

Yu. V. Mikhatskii

Peak diode voltmeters are widely used for measuring pulse voltages. In these voltmeters the pulse voltages are first converted by means of peak diode-detectors into a direct voltage which is next fed to the very high impedance input of a special measuring device (Fig. 1). Reflex circuits are often used as high impedance devices (a tube reflex voltmeter is shown in Fig. 2). In addition to the high input impedance the reflex voltmeter possesses other advantages; a linear scale, wide range of measurement, stable calibration with different tubes and variations of the supply voltage.

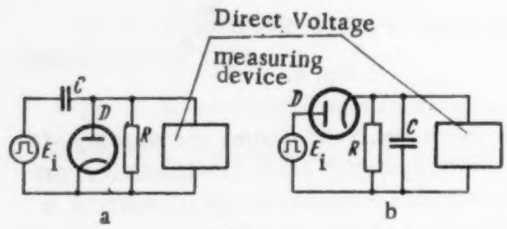

Fig. 1.

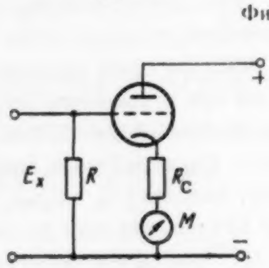

Fig. 2.

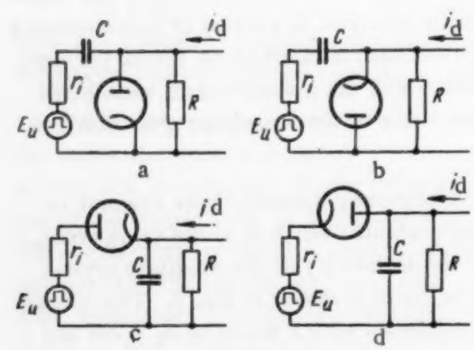

Fig. 3.

The operation of a pulse voltmeter, consisting of a peak diode detector and a reflex circuit, is affected by diode initial current and the grid current of the reflex tube. The combined action of these two currents determines to a considerable extent the zero stability of the voltmeter, the stability of its readings, and the input impedance of the reflex tube. The present article analyzes this effect and, in this connection, the best design of pulse diode voltmeters.

It is known that the initial current of a diode is due to the initial velocity of the electrons leaving the cathode. For negative anode voltages the diode volt-ampere characteristic is well approximated by the exponential of the form:

$$i_d = I_0 e^{kU_d}, \qquad (1)$$

where i_d is the diode current;

U_d is the diode voltage;

I_0 is the current flowing through the diode with a zero potential between its electrodes (normally tens or hundreds of microamperes);

k is a constant depending on the material of the cathode (for oxide cathodes k = 8 to 10).

With negative grid voltages the grid current of receiving amplifier tubes consists of several components, the principal being the electron and ion components, the thermionic current, and conduction current. If the negative grid potential of the tube is greater than 1-1.5 v in its absolute value, the ion component and the thermionic current become predominant and the grid current flows in the negative direction. Precisely such a condition is characteristic for a reflex voltmeter tube. The negative current attains 10^{-8} to 10^{-9} amp, and under the effect of various causes it varies gradually [1]. It is this last circumstance which may cause a troublesome effect.

At first let us examine how the variations of the grid current affect zero stability. For this purpose let us analyze for various pulse diode voltmeter circuits the conditions necessary to establish before the reception of a signal.

Figure 3 shows the direction of currents in the four possible (simplest) types of this circuit. Taking into account that in the initial condition the resistance of the diode is, as a rule, considerably larger than the internal

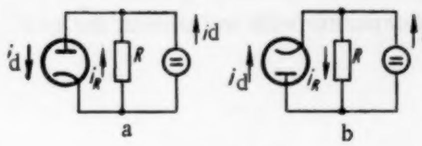

Fig. 4.

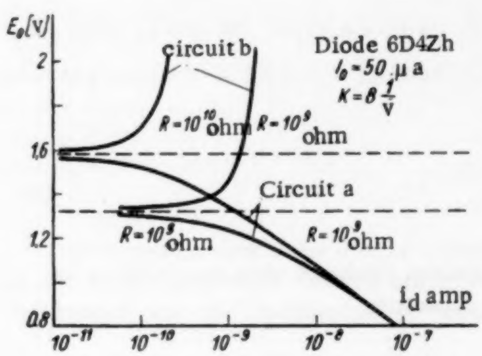

Fig. 5.

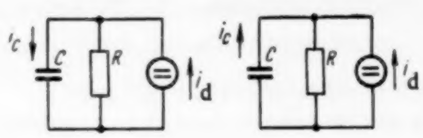

Fig. 6.

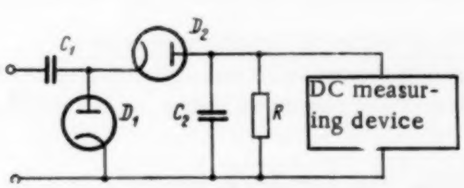

Fig. 7.

resistance of the pulse source [2], the latter can be neglected and all the four conditions reduced to two equivalent circuits (Fig. 4). Circuits of Figs. 3a and 3d can be reduced to those of Fig. 4a (the anode of the diode is connected to the grid of the measuring tube) and circuits of Figs. 3b and 3c to those of Fig. 4b (the cathode of the diode is connected to the grid of the tube).

For the circuits of Fig. 4a we have

$$i_g = i_d + i_R;$$
$$E_0 = i_R R.$$

Here E_0 is the voltage at the input of the reflex circuit without a signal;

i_g is the tube grid current;

R is the load resistor (taking leakage into account);

i_R is the current flowing through the load resistor.

From these equalities in conjunction with the volt-ampere characteristic of the diode (1) we obtain:

$$E_0 = -(I_0 R e^{-k E_0} \quad i_g R). \tag{2}$$

For circuit of Fig. 4b the following equations hold:

$$i_g + i_d = i_R,$$
$$E_0 = i_R R,$$

whence in conjunction with (1) we obtain

$$E_0 = I_0 R e^{-k|E_0|} i_g R. \tag{3}$$

Figure 5 shows graphs of the initial biasing calculated from (2) and (3) for the two equivalent circuits. It will be seen from the curves that where the grid of the measuring tube is connected to the anode of the diode (Fig. 3a and 3d) the initial biasing depends but little on the grid current. Therefore a voltmeter constructed in this way has a very small zero drift even with considerable variations in the grid current. Circuits in which the grid of the measuring tube is connected to the cathode of the diode (Figs. 3b and 3c) may have a considerable zero drift. As long as the grid current is small (either equal to or smaller than the diode initial current) the initial voltage on the grid changes but little with grid current. But when the grid current begins to exceed the initial diode current, the voltage on the grid changes almost proportionately to the grid current. As the result of this the zero reading begins to drift. In addition, the formation of a positive voltage on the diode cathode leads to additional errors when the pulse voltage is converted into a direct voltage.

Let us now examine the condition which will arise in the circuit when a signal is received. During the operation of the pulse the peak diode detector capacitor charges. Since the charge current is always considerably larger than the grid current, the effect of the latter on the charging can be neglected. In the intervals between pulses the capacitor discharges; the discharge current is comparable with grid current.

In the circuits of Figs. 3a and 3d the capacitor voltage after charging is negative with respect to the grid. This condition is represented on the equivalent discharge circuit, Fig. 6a. In the circuits of Figs. 3b and 3c the capacitor voltage after charging is positive; this case is represented by the circuit in Fig. 6b.

It is obvious that in the circuit of Fig. 6a the grid current speeds up the discharge of the capacitor. This is

equivalent to a reduction of the input impedance of the reflex circuit. The relative speeding up of the discharge is determined by the relation of the currents which flow through the capacitor with and without the grid current:

$$\frac{\frac{U_C}{R}+i_g}{\frac{U_C}{R}}=1+\frac{i_g R}{U_C},$$

where U_C is the voltage across the capacitor.

The equivalent discharge resistance is

$$R_{eq}=\frac{R}{1+\frac{i_g R}{U_C}}. \tag{4}$$

With an unlimited rise in the nominal discharge resistance R, the equivalent discharge resistance tends to its limit, which is determined by the grid current and voltage across the capacitor:

$$R_{eq.max}=\lim|R_{eq}|_{R\to\infty}=\frac{U_C}{i_g}. \tag{5}$$

In the circuit of Fig. 6b the grid current decreases the speed of the capacitor discharge. The relative retarding of the discharge is represented by expression

$$\frac{\frac{U_C}{R}-i_g}{\frac{U_C}{R}}=1-\frac{i_g R}{U_C}.$$

The equivalent discharge resistance is

$$R_{eq.}=\frac{R}{1-\frac{i_g R}{U_C}}. \tag{6}$$

For small grid currents the retarding of the discharge may be useful. With $i_g \approx U_C/R$, however, the voltmeter readings become unstable.

Let us now compare the result so far obtained. The circuits shown in Figs. 3a and 3d provide good stability both for the zero reading and voltmeter indications over a wide range of grid current variations. The variations of the discharge resistance peculiar to this circuit will, with correctly chosen parameters, cause negligibly small variations in the voltmeter reading. Circuits shown in Figs. 3b and 3c have no zero drift and provide stable readings only at small values of the grid current. If $i_g > [0.5\text{-}1]$ v/R, the circuit acquires a zero drift. If in addition $i_g \approx U_C/R$, the voltmeter readings also become unstable.

Therefore peak diode voltmeters should be designed in such a way that the grid of the measuring tube is connected to the anode of the diode; for measuring positive pulses the parallel connection should be used, and for negative the series one. In order to measure the full pulse swing the circuit should be designed as shown in Fig. 7. If necessary, the load resistance can be omitted without fear of zero drift; the capacitor in this case will discharge through the leakage resistance of the grid.

Tests fully confirmed these conclusions.

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ACOUSTICAL MEASUREMENTS

CALIBRATION OF INFRASONIC HYDROPHONES BY THE RECIPROCITY METHOD IN SMALL WATER CHAMBERS

A. G. Golenkov

The present work deals with an experimental apparatus for calibrating infrasonic piezoelectric hydrophones by the reciprocity method, which was developed by the All-Union Scientific Research Institutes of Physicotechnical and Radiotechnical Measurements (VNIIFTRI).

Hydrophones are usually calibrated at infrasonic and low frequencies in closed small chambers filled with water [1, 2].

When hydrophones are calibrated in small water chambers it is impossible to consider the chamber and the converters themselves as rigid bodies, and it is necessary in determining the reciprocity parameters to take into account their acoustical impedance.

Thus, the main difficulties in the reciprocity method consist in evaluating the indefinite coupling (by the chamber and converters) between the interacting converters and estimating their input resistance or compliance.

In the VNIIFTRI equipment a resonance method of determining the dynamic flexibility of the system is used. In order to extend the frequency range, prevent the spilling of the meniscus, and reduce the losses, a weak excitation of the resonator by means of a hard piezoelectric radiator with a small acoustical output is used.

Resonance method of determining the reciprocal parameters of a system. A theoretical analysis [3] of calibration by the method of reciprocity in a small chamber leads to the following expression for the reciprocity parameter (H), which forms part of the formula representing the sensitivity of the hydrophone:

$$H=j\frac{V\omega}{\rho c^2}+\left(\frac{1}{\zeta_o}+\frac{1}{\zeta_x}\right), \tag{1}$$

where $-j\rho c^2/V\omega$ is the acoustical resistance of the chamber;

ζ_0 is the acoustical resistance of the reversible converter;

ζ_X is the acoustical resistance of the converter to be calibrated.

Owing to the small compressibility of water it is impossible to neglect the term $(1/\zeta_0 + 1/\zeta_X)$ as compared with $j\,V\omega/\rho c^2$. Therefore the determination of the reciprocity parameter amounts to measuring the acoustical compliance of the whole system, consisting of the chamber and converters, which at low frequencies (up to the first resonance frequency of the system) operate in a condition of flexibility.

In order to determine the reciprocity parameter of the system it is necessary to measure the total acoustical dynamic flexibility (C_a) of the system:

$$H=j\omega(C_K+C_O+C_X)=j\omega C_a, \tag{2}$$

where C_k is the flexibility of an enclosed volume of water (taking into account the compliance of the chamber walls);

C_0 and C_X – the flexibility of diaphragms of the reversible converter and the one being calibrated, respectively.

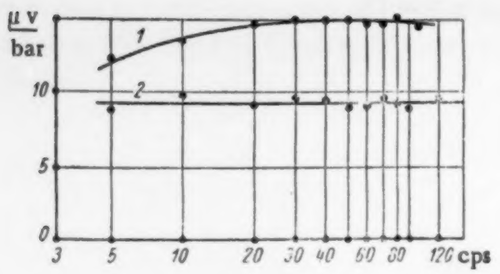

Fig. 1.

There is no need to separate flexibilities C_k, C_0 and C_x during calibration, since the filling of the chamber with water and the measurements are made when the hydroacoustical converters are already placed in the chamber; all the factors (compressibility of the medium, deformation of the chamber walls) are thus being taken into consideration.

The question arises whether it is possible to replace the determination of the dynamic flexibility by static flexibility $C = \Delta V / \Delta p$, i.e., the ratio of the displacement volume to the excess static pressure. Such measurements may become complicated by the effect of additional flexibilities which do not appear in calibration. An exact estimation of these flexibilities is difficult, and this is a source of additional errors in calibrating hydrophones.

Experience has shown that the quality of packings, resistance of slots, properties of converters, and behavior of air bubbles in water can differ under static and dynamic conditions, thus leading to considerable errors in determining the sensitivity of hydrophones.

As a confirmation of the above we have plotted in Fig. 1 the frequency characteristics of the same piezoelectric hydrophone obtained when it was calibrated by the hydroacoustical press method* in the presence of narrow slots (of the order of 0.6 mm) in the chamber packing (curve 1) and without them (curve 2).

The sloping of the frequency characteristic of curve 1 at low frequencies and a considerable rise in sensitivity at higher frequencies is due to the rise with frequency of the slot resistances in the dynamic condition; this effect led to a decrease in the flexibility of the system and a rise in pressure which was determined in calibrating the chamber under static conditions.

In the equipment in question the calibration of hydrophones by the reciprocity method was carried out by means of resonance determination of the dynamic flexibility. For this purpose the small water chamber was supplied with a thin tube of constant cross section which was placed in a vertical position.

A system consisting of a measuring chamber filled with water and a tube is an air-water resonator, similar to a Helmholtz resonator.

In the low frequency range its resonance frequency is determined by the flexibility (C_a) and mass of water in the narrow tube. Variation of the height of the water column in the tube, calibrated in terms of the mass of water, provides a means to control the resonance frequency and obtain resonance vibrations of the system at the frequency required for the calibration of the hydrophone.

There exists a simple relation between the variations of the mass of water in the tube and changes in the resonant frequency; this relation makes it possible to determine the dynamic flexibility of the system by means of frequency measurements.

By using the difference of resonating masses it becomes possible to avoid the evaluation of the effective (connected) mass at the bottom of the tube and exclude it from the determination of flexibility.

The mechanical flexibility C_f of the system with this differential method will be represented by the formula:

$$C_f = \frac{1}{\Delta m}\left(\frac{1}{\omega_{02}^2} - \frac{1}{\omega_{01}^2}\right), \tag{3}$$

where $\Delta m = m_2 - m_1$ is changes of the mechanical mass of water in the tube;

ω_{01} and ω_{02} are the resonance angular frequencies of free oscillations of the system for the initial and final water level in the tube, respectively; $\omega_{02} < \omega_{01}$.

Taking into consideration attenuation mainly due to friction losses of the liquid in the tube, and changing

*The hydroacoustical press method was developed by A. D. Brodskii at the D. I. Mendeleev All-Union Scientific Research Institute of Metrology.

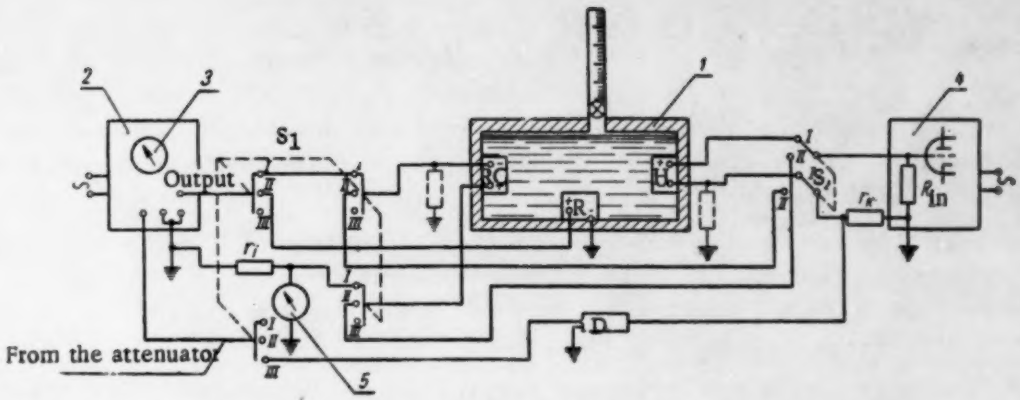

Fig. 2. Block schematic for calibration of infrasonic piezoelectric hydrophones by the reciprocity method. Positions of the switch S_1: I) measurement of the current flowing through the reversible converter in the radiating condition; II) supply of the auxiliary radiator; III) calibration of the output voltage in the open-circuit condition of the hydrophone under calibration and the reversible converter; r_k) additional resistance which is switched into the converter circuit when the output voltage is calibrated; r_i) resistance whose voltage drop is measured when it carries the current flowing through the reversible converter in a radiating condition.

from mechanical resistances (mechanical mass and flexibility) to acoustical ones, we obtain the final equation for determining the acoustical dynamic flexibility of the system

$$C_a=\frac{1}{4\pi^2}\cdot\frac{S^2}{\Delta m}\left[\frac{1}{f_2^2-\left(\frac{\Delta f_2}{2}\right)^2}-\frac{1}{f_1^2-\left(\frac{\Delta f_1}{2}\right)^2}\right], \quad (4)$$

where f_1 and f_2 are the resonance frequencies of the system with the initial and final water levels in the tube;

Δf_1 and Δf_2 - the bandwidth of the respective resonance;

S is the cross-sectional area of the resonator tube.

In order to determine Δm and S the tube is first calibrated by weighing pure mercury on a precision analytical balance and graduating it in values of mass. In practice it is convenient to calibrate it in values of $1/4\pi^2 \cdot S^2/\Delta m$, having first selected the constant initial water level.

The advantage of the resonance method of determining the flexibility of the chamber is the rise of sound pressure in the chamber due to resonance. This effect makes the excitation of the chamber much easier; in particular it provides the possibility of exciting the chamber by means of a hard piezoceramic radiator. Such hard converters have a simple acoustical impedance (flexibility) over the entire infrasonic and low frequency range.

For determining the dynamic flexibility of normal water chambers used for hydrophone calibration, it is only necessary to add to them a narrow tube, since the circuit of the hydrophone under calibration can be used as a resonance indicator.

The advantage of the above method of determining the dynamic flexibility consists in completely preserving the dynamic nature of the reciprocity parameter measurements in the subsequent calibration of hydrophones; moreover these measurements do not interfere with the electrical character of hydrophone calibrations according to the reciprocity method.

The determination of the total dynamic flexibility provides a practical criterion of the quality of filling the chamber with water from the point of view of air bubble content, which may be important for the use of small measuring equipment with small chambers.

Description of the equipment for calibrating hydrophones by the reciprocity method. Figure 2 shows a developed block-schematic diagram of the equipment for calibrating infrasonic hydrophones by the reciprocity method.

The small measuring (water) chamber 1 is a thick-walled steel cylinder with walls 40 mm thick. Its internal diameter is 130 mm and length 200 mm (in this equipment the chamber of the hydroacoustical press constructed by the VNIIM was used).

Before being filled with water the chamber is closed with a massive steel lid, which carries in its center a reversible converter RC. An auxiliary radiator R and the hydrophone under calibration H are placed at the bottom of the cylinder. Spherical radially polarized converters made of a barium titanate ceramic serve as the reversible and auxiliary R converters (they are 50 and 40 mm in diameter, respectively).

At small voltages (of the order of 100 v) on the coating of the auxiliary radiator the level of sound pressure in the chamber reaches several hundred bars (400 bars) during calibration.

The auxiliary radiator R and reversible converter RC are fed from the same oscillator 2. The switching is done by means of switch S_1.

Voltmeter 3 serves to measure accurately the open circuit voltage of the converter by the substitution method. In these measurements the high impedance voltmeter 4, which is connected to the output of the converters by means of switch S_2, is used as an output indicating instrument. The same voltmeter serves to find the point of resonance of the system and its detuning to the 0.707 level of the peak tuning (for the correct bandwidth) when the dynamic flexibility of the system, excited by the auxiliary radiator, is being determined.

In order to overcome the circuit difficulties which arise from the need to use the substitution method in the infrasonic range, the reversible converter and the one under calibration are grounded directly, and their bodies are insulated from the chamber by means of insulating bushings.

Such an insulation is not difficult to attain (the sensitive elements of the piezoelectric ceramic hydrophones are usually coated by a waterproof insulation), since the leakage to ground resistance R_L (shown in a dotted line on the circuit) can be easily made much larger than r_k.

Tests have shown that in the frequency range under consideration R_L remains constant and for $R_L \gg r_k$ does not affect the accuracy of measurements of the open circuit voltage of converters, thus providing the possibility of using the normal calibration circuit.

In this case the current through the reversible converter (Fig. 2, position I of switch S_1) is measured by the voltage drop across resistor r_i (r_i is considerably smaller than the voltmeter 5 resistance).

The external resistance potential divider D is used to supplement the attenuator when a very small calibrating voltage has to be fed to r_k from oscillator 2.

Switching is carried out during measurements by means of switches S_1 and S_2; in calibration a switch incorporated in oscillator 2 is also used for switching voltmeter 3 to the output of the attenuator. The calibration procedure is normal and the sensitivity is calculated from the usual formula

$$E=\sqrt{\left(\frac{U_x}{U_o}\right)_I \left(\frac{U_x'}{I_o}\right)_{II} H\cdot 10^{-7}} \left[\frac{\text{v}}{\text{bar}}\right]. \tag{5}$$

where U_x, U_x' and U_0 are open circuit voltages of the converter under calibration (x) and the reversible (0) converter;

I_0 is current of the reversible converter in the radiating position.

Evaluation of the accuracy of calibration of infrasonic hydrophones. First the accuracy of formula (4) for determining the reciprocity parameter was checked. For this purpose the relation of the reciprocal of the square of actual resonance frequencies of the system to the mass of water in the resonator tube was obtained experimentally.

When corrections for attenuation were applied it was found that, despite the very low Q factors of the system

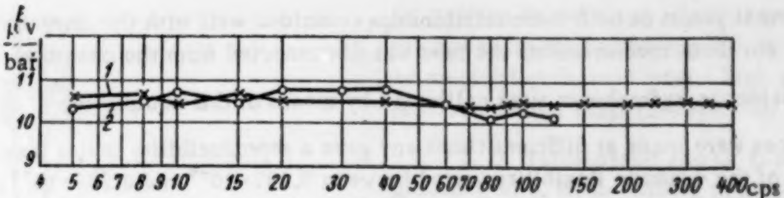

Fig. 3.

(for instance, at 5 cps $Q_s \geq 3.7$), these corrections do not disturb to any appreciable degree the linearity of the relationship thus obtained. The largest deviation from the straight line of all the tubes used was 0.3 db. The frequency resonance characteristic was taken with a constant current through the piezoelectric ceramic radiator.

The shape of the characteristic as predicted by theory for systems with a lumped mass and elasticity was fully confirmed in practice; the pressure in the chamber increases monotonically as the curve approaches resonance, and after the resonance peak remains constant (the frequency characteristic was taken up to 2000 cps). This check was also useful to ascertain that there are no additional resonance points in the system.

These experimental results confirm that it is possible to consider, in the range of low frequencies, the air-water resonator in a linear approximation as a system with a lumped mass and elasticity.

Taking into consideration the possibility of slow changes in the flexibility of the chamber volume (for instance, due to air bubbles), an evaluation of the reproducibility of results in measuring dynamic flexibility was made. The reproducibility was studied as usual on a series of consecutive measurements (not less than 12) taken in 1.5-2 hours.

In order to eliminate random variations of the flexibility of the chamber, the water was poured into the tube through its open end up to a chosen mark, or emptied through a tap at the bottom of the tube and outside the chamber down to the same mark. The largest deviation of the flexibility measurements was 0.7 db, the mean-square-error of a number of measurements amounted to 3%.

In view of the low value of the Q factor in this frequency range it is interesting to evaluate the systematic error in determining the dynamic flexibility (C_a) due to neglecting the effect of losses.

Let us insert into (4) the Q values determined at the appropriate resonance of the system:

$$C_a = \text{const}\left[\frac{1}{f_2^2\left(1+\frac{1}{4Q_2^2}\right)} - \frac{1}{f_1^2\left(1+\frac{1}{4Q_1^2}\right)}\right] = \text{const}\left[\frac{1}{f_2^2} - \frac{1}{f_1^2} + \frac{1}{4}\left(\frac{1}{Q_1^2 f_1^2} - \frac{1}{Q_2^2 f_2^2}\right)\right]. \tag{6}$$

Error δ due to neglecting the losses can be found in the following manner: for $Q_2 < Q_1$

$$\delta\% = -\frac{25}{Q_2^2}\cdot\frac{1-\left[\frac{Q_2}{Q_1}\cdot\frac{f_2}{f_1}\right]^2}{1-\left[\frac{f_2}{f_1}\right]^2} \tag{7}$$

The negative signs means that the flexibility obtained is a little larger than its actual value.

In the worst case the value of the error, calculated from experimental data, did not exceed 2%.

The linearity of the reversible converter and the closed volume (the coupling element between them) was also checked. In the first case we checked the relation of the current of the reversible converter in a radiating condition to the excitation frequency (the curve was obtained in the circuit described; see Fig. 2) with a constant voltage at the converter terminals (120 v).

In order to confirm the linearity of the system in the second case, the relation between the current through the reversible converter in a condition of radiation and the corresponding output voltage of the converter under calibration were checked.

The experimental points of both these relationships coincided well with the lines drawn through the origin of the coordinates. For these measurements the tube was disconnected from the chamber.

Several piezoelectric hydrophones were calibrated by means of this equipment.

The calibrations were made at different times and gave a reproducibility better than 0.5 db, despite the fact that the values of the dynamic flexibility varied between $0.197 \cdot 10^{-6}$ and $0.276 \cdot 10^{-6}$ $cm^4 \cdot sec^2/g$.

By way of an example, Fig. 3 shows the calibration results of a piezoelectric hydrophone (curve 1) and for comparison a frequency characteristic of the same hydrophone obtained by the hydroacoustical press method (curve 2).

The methods were compared in the same chamber. The results became comparable only after a careful preparation of the chamber. In order to eliminate cracks, hard lead packing was used for the converters and a best possible piston was selected with a minimum gap, thus ensuring a large time constant for the system.

Despite the adopted precautions, the flexibility of the system, determined in calibrating the chamber of the hydroacoustical press in the static condition, was larger than the dynamic flexibility, determined by the resonance method, by 5 to 8%; this can probably be explained by the effect of the flexibility of the tubes which connected the chamber to the compensator and the manometer when determining the static flexibility of the chamber.

Figure 3 shows a good agreement between hydrophone calibration by means of two independent methods: that of the hydroacoustical press and the reciprocity method in the range of 5 to 120 cps (the range covered by the hydroacoustical press equipment).

By using tubes with an internal diameter of ~ 2 mm it was possible to obtain resonance vibrations of the chamber at frequencies above 100 cps.

In taking the frequency characteristic the absence of additional resonances was ascertained up to 2000 cps. Hence the calibration of hydrophones on the equipment here described can be carried out at frequencies considerably in excess of 100 cps. In calibrating hydrophones up to 400 cps a constant sensitivity was obtained (Fig. 3).

The work was conducted under the guidance of L. G. Rusakov.

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A SET FOR MEASURING ULTRASONIC FIELDS IN LIQUIDS

I. N. Kanevskii

At present one often encounters problems in the measurement technique involving the establishment and analysis of ultrasonic fields with a complex form, including those produced by focusing radiators and focusing systems. For a detailed investigation of such fields it is necessary to have a receiver whose dimensions are smaller than the wavelength in the medium and an accurate coordinate-measuring device for its displacement. Moreover

for working in the range of small amplitudes, to which the linear theory can be applied, it is necessary to have an amplifying channel with a high gain, since the signals received from a miniature receiver are weak.

B. D. Tartakovskii and G. L. Kaminir, under the guidance of L. D. Rozenberg produced, in the Physics Institute of the Acad. Sci.,USSR,a model of an apparatus by means of which the distribution of ultrasonic fields in liquids could be obtained manually point by point. On the basis of the experience gained with this coordinate-measuring device the equipment described in this article was made; in its development the main attention was paid to accuracy of measuring linear and angular coordinates, decreasing the size of the receiver, and making its operation automatic.

The most complicated part of the equipment is the coordinate measuring device (Fig. 1).*

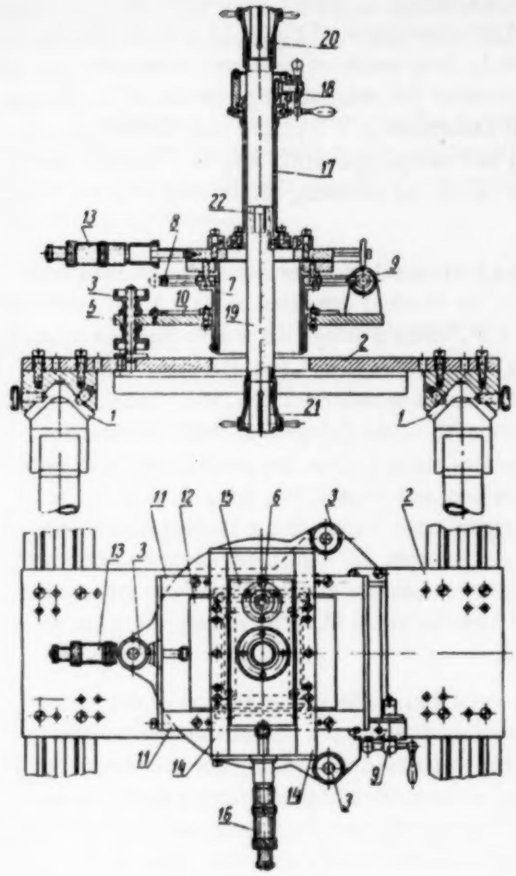

Fig. 1.

Base plate 2 is fixed on two knife-edge bearings 1, by means of which the coordinate-measuring device is mounted on an optical bench; three set screws 3 and clamping screw 4 are on the base plate. Plate 5 is placed accurately into a horizontal position by means of set screws 3 and level 6. In the middle of plate 5 there is a socket 7, which carries gear wheel 8 with worm drive 9. This device provides the possibility of rotating the object attached to the coordinate-measuring unit through 360°. The angle of rotation is read off dial 10 with 2° graduations. For accurate measurements a vernier scale is provided with 5' graduations. Gear wheel 8 carries horizontal runners 11 to which plate 12 is fixed. Both the plate and the runners are made of hard steel. The plate moves along the runners on steel balls fixed in a cage, thus providing minimum friction and practically no free play. Plate 12 is moved by means of a micrometer screw 13. Plate 12 carries another pair of horizontal runners 14 with plate 15 and micrometer screw 16; plates 12 and 15 move at right angles to each other. The accuracy of measuring the movements of the micrometer screws 13 and 16 is 0.01 mm. Plate 15 carries stand 17 inside which tube 19 can be displaced vertically by means of two bevel gears 18. The top and bottom ends of the tube have split sockets 20 and 21 which serve to hold a receiver or a radiator. Tube 19 has a millimeter scale with a vernier 22 which reads vertical displacement with an accuracy of 0.1 mm. By means of handles fixed to the worm-gear drive 9, the micrometer screws 13 and 16, and the bevel gears 18 it is possible to displace the object held in the split socket manually in three mutually perpendicular directions and rotate it about a vertical axis.

The coordinate-measuring device can be used in other equipment., for instance, when investigating the distribution in space of electromagnetic fields, temperatures, and other physical quantities.

For an automatic recording of the measurements it is necessary to move the coordinate-measuring device drives with uniform speed. For this purpose selsyns are used. A selsyn drive has several advantages over a motor drive: it is simpler to mount, since only the selsyn itself (without the reduction gear) need be fixed to the drive of the coordinate-measuring device; for the reduction and control of speed only one reduction gear is required; any motor can be used for the primary drive, providing it has the required power and stability of speed. In this equipment synchrotransmitter ND-501 was used, driven by a 30 watt motor type DVA-UZ through a three-stage reduction drive which provided three speeds of operation. For the rotation and vertical displacement of the coordinate-measuring device synchrorepeaters NS-501 were used, and for horizontal displacement synchrorepeaters NS-404. The selsyns are either placed on the optical bench or suspended from brackets and connected

*The device was developed by Z. G. Levin.

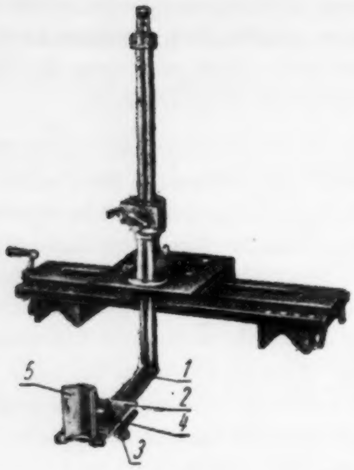

Fig. 2.

to the coordinate-measuring device by means of flexible drives. For an automatic stopping of the movement of plates 12 and 15 (see Fig. 1) end switches are provided in their extreme positions; these switches operate relays which disconnect the magnetizing circuits of the selsyns. The control equipment is assembled as a separate unit which includes a step-down transformer, two relays type MKU-48, 24 v rectifier for feeding the relays, and a switch for reversing the direction of the synchrorepeaters.

In manual operation, horizontal displacements can be read with an error up to 0.01 mm; in the vertical direction up to 0.1 mm with the angular error equal to 2.5'. With a selsyn drive it is possible to select by means of the gear box speeds of 124, 247, and 370 rpm. They correspond to linear displacement speeds of 1.03, .206, and 3.08 mm/sec, and angular velocities of 2, 4, and 6 deg/sec. With automatic starting of the coordinate-measuring system the absolute error in estimating the initial position does not exceed 30', i.e., 0.25 mm. In automatic stopping the largest error occurs in the turning movement, since in this case the moment of inertia of the system is greatest. At 124 rpm the maximum absolute error is 6' and the mean error does not exceed 2.7'; at 247 rpm the maximum error does not exceed 2' and the mean error 1'; and finally, at 370 rpm the maximum error is not more than 10' and the mean 3'. The stabilizing time of the rotary movement does not exceed 1 sec at a high rotation speed.

The device[1] with small modifications is used as measuring amplifier. The linear portion of the instrument scale was extended by increasing the gain of the high-frequency amplifier; the output transformer was changed for a choke coil, an output with a logarithmic potentiometer was added for feeding the low-frequency signals to the recorder; a cathode follower and an output for feeding an amplified high-frequency signal to an oscillograph or a v-t voltmeter were also added. It was pointed out in [1] that the set is designed for amplifying amplitude-modulated signals. After detection and amplification the audio-frequency envelope is fed to an automatic level recorder (for instance, of the Neumann type), which normally operates in the frequency range of 30 cps to 20 kc. If measurements are made with unmodulated signals, the control grid of the last high-frequency amplifier tube is supplied through a special input with a modulating voltage from an audio-frequency oscillator type ZG-11, in order to provide normal operating conditions for the recorder. For recording measurement results without frequency transformation it is possible to feed the signal from the high-frequency output of the amplifier to cathode-ray oscillograph type ÉNO-1 and photograph its screen at a slow scanning speed (minimum scanning speed is of the order of 0.07 cps).

The measuring amplifier has the following characteristics. For a modulated signal with a modulation factor of 70% the minimum sensitivity of the amplifier is 8 μv, and its dynamic range 16 db. For an unmodulated signal input and modulation supplied by the ZG-11 oscillator with a 400 cps voltage of 10 v, the dynamic range remains the same, but the sensitivity decreases to one-tenth. The threshold sensitivity of the high-frequency amplifier is of the order of 0.5 mv, its dynamic range is 32 db, and its frequency characteristic in the range of 300 kc to 2.5 Mc is flat within 1.5 db. The preamplifier has a gain of 70 and a flat frequency characteristic within the range of 300 kc to 3 Mc.

For measuring ultrasonic fields of liquids a rectangular container of $100 \times 40 \times 40$ cm^3 was used. In order to decrease reflections from the bottom and the walls of the container absorbing coverings were used; the walls of the container were covered with rubber; in front of them "Venetian blinds" made of the same rubber were placed; falling on such a "blind" the sound undergoes multiple reflection and, absorbed by the rubber, is reflected from the walls and the bottom with a considerable attenuation.

Two standard optical benches are fixed to the measuring container for the purpose of holding a light and coordinate-measuring device with a receiver and radiator.

For fixing cylindrical radiators in the measuring container a special coordinate-measuring device is used; the radiator holder (Fig. 2) is fixed to the optical bench of the container by means of knife-edge bearings in the same manner as a precision coordinate-measuring instrument. Bracket 1 of the holder has a plexiglas plate 2, which is placed accurately in a horizontal position by means of three screws 3 and a detachable level 4, and

carries a cylindrical radiator 5. Owing to the accurate horizontal positioning of the precision coordinate-measuring device and that of the radiator holder plate, the same relative positioning of the radiator and receiver is achieved, which is necessary in order to obtain a correct picture of radiator field and consistent measurement results.

A miniature probe [2] was used for a receiver. The diameter of the receiving head of the probe was 0.2 mm. The probe is connected to the preamplifier which consists of two voltage amplifying stages and a cathode follower. The amplifier is placed in a brass tube to whose lower end the probe is attached by means of a hermetically sealed joint.

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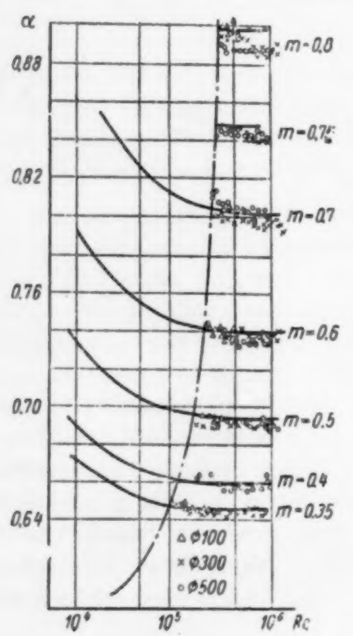
ERRORS IN THE BASIC DIAPHRAGM DISCHARGE COEFFICIENTS

S. S. Kivilis

In compiling regulations 27-54 [1] the values of the basic diaphragm discharge coefficient were taken from the German standard for measuring discharges [2], since the data for this standard, which was obtained as the result of many years of study by R. Witte [3, 4, 5], became the basis for similar standards of a number of other European countries including Italy [6], Britain [7], France [8], and Poland. In analyzing the available materials on diaphragm discharge coefficients, however, one arrives at the conclusion that up to the present no detailed experimental data have been published which confirm the correctness of the adopted values for the discharge coefficient on the one hand and of the errors ascribed to them on the other hand.



Moreover the little data available on this question which are contained in periodic publications and documents of the International Standards Organization ISO/TK30 not only do not justify the discharge coefficients specified in the national standards, but sometimes actually contradict them.

As early as 1936, in comparing the data of the German standard with certain experimental results, Engel and French [9] established that the discharge coefficients adopted in Germany for diaphragms with a modulus* of 0.45 and larger exceed, it would appear, the real values by about 0.3%, and that additional tests are, therefore, required in order to check these coefficients.

Such tests were subsequently undertaken by R. Witte, as is apparent from the text of the proposals made by Germany to the ISA conference in 1939 [5]; no materials referring to these experiments could, however, be found in the technical literature, with the exception of one graph (see figure), which partially reflects the results obtained by Witte and constitutes the supplement to the proposals [5].

In [10] Witte notes that the German standard of 1943 is based on the results of the new investigations included in [5]. Not having the full material of these investigations, we cannot compare them with the data of the German standard; a visual inspection, however, of Witte's graph (see figure) shows that the discharge coefficients adopted in Germany (see Table 1, column 7) do not correspond with the experimental results for certain values of the modulus. The position of experimental points for moduli of 0.5 and 0.6 indicate that the real discharge coefficients are smaller than the accepted ones.

It should also be noted that the coefficients proposed by Germany in [5] also do not correspond to the results shown in the figure for moduli of 0.5 and 0.6 (see Table 1, column 5).

These discrepancies could possibly be explained by the imperfect technique used by Witte [11] in working out the experimentally obtained results. For a given modulus of a constricting device, several series of experiments were carried out with different Reynolds numbers, with every series corresponding to a certain pipeline

*Here and subsequently we shall take as the modulus of the tapering device the quantity $m = d^2/D^2$ [1].

TABLE 1

Modulus m	Basic discharge coefficient α					
	Witte, 1930 [3]	Witte, 1934 [4]	ISA, 1935 [6]	Proposals by Czechoslovakia and Germany 1939 [5]	Italian [6] British [7] and French [8] standards	German standard [2]
1	2	3	4	5	6	7
0.05	0.598	—	0.598	0.598	0.598	0.598
0.1	0.602	—	0.602	0.602	0.602	0.602
0.15	0.6075	—	0.608	0.608	0.608	0.608
0.2	0.615	—	0.615	0.615	0.615	0.615
0.25	0.624	—	0.624	0.624	0.624	0.624
0.3	0.634	—	0.634	0.634	0.634	0.634
0.35	0.646	—	0.646	0.646	0.646	0.645
0.4	0.661	—	0.661	0.660	0.660	0.660
0.45	0.676	—	0.677	0.676	0.676	0.676
0.5	0.696	—	0.696	0.694	0.695	0.695
0.55	0.717	—	0.717	0.715	0.716	0.716
0.6	0.742	0.742	0.742	0.740	0.740	0.740
0.65	0.770	0.770	0.770	0.768	0.768	0.768
0.7	0.806	0.804	0.806	0.802	0.802	0 802
0.75	—	0.848	—	—	—	—
0.8	—	0.898	—	—	—	—

diameter. For each series of experiments a mean curve was drawn and from all the mean curves one common ("normal") curve, which held for one modulus and several pipe diameters. The basic error of the obtained discharge coefficients was taken as the maximum deviation of the mean curves from the common curve.

TABLE 2

Specification	Parameter evaluating the basic diaphragm discharge coefficient	
	Description	Numerical value
German standard [2]	Basic tolerance (grundtoleranz)	±0.5% at m < 0.35 ±1% at m = 0.7
Italian standard [6]	Probable basic error (errore probabile base)	± 1%
British standard [7]	Basic tolerance (basic tolerance)	±0.75% at m ≤ 0.55 ±2.5% at m = 0.7
French standard [8]	Mean-square error	± 1%*
ISA rules [16]	The largest expected error (grösster zu erwartender Fehler)	±1%
Proposed norms of the VTÍ [17]	Tolerance	±0.5% at m < 0.5 ±1% at m = 0.7
Rule No. 169 [18]	Basic probable error	±0.5% at m < 0.55 ±1% at m = 0.7
Rules 27-54 [1]	Mean-square error	0.5% at m < 0.35 1% at m = 0.7

*The signs ± are given in the original of the standard.

It should be noted that not only Witte but also other investigators did not use statistical methods for calculating the values and errors of discharge coefficients in studying the discharge-measuring constricting devices with an "angular" selection of pressure. In this connection, both in literature and specifications the question of errors remained very involved and unclear. In various papers one can find different arbitrary terms for describing accuracy of the discharge coefficients, such as: error, tolerance, dispersion, probable error, mean-square error, etc, but the method of obtaining these values is not indicated in a single instance. Thus, in [12] it is stated that the mean error (?) obtained for the discharge coefficients for Reynolds numbers exceeding the limiting values amounts to ±0.5% for water and ±1% for air. In [3] the dispersion (?) of the measurement results is given as 0.5%. According to [13] the discharge coefficients obtained can be used (without calibrating the diaphragms) with a reliability (?) of at least 1%. Finally in [4] it is noted that for every point which is a mean of 6-10 measurements the dispersion (?) is ±0.03% and the general tolerance (?) ±1%. The unclear meaning of the term "tolerance" has been subsequently admitted by Witte himself [14].

The question of errors is just as confused in the national specifications for measuring discharge, as can readily be seen from Table 2. It should also be noted that in Rousselet's opinion [15] the error of the discharge coefficient cited in the German standard and the works of Witte are underestimated (for commercial reasons). At the same time Jorissen considers [11] that in the French standard the errors are exaggerated.

The author of this article worked out mathematically Witte's experimental data for basic diaphragm discharge coefficients (see figure) which led to the following results.

If it is assumed that Reynolds limiting numbers fall on the dash-dot line shown in the figure (for details in this connection see [19]), i.e., that to the right of this line the discharge coefficients do not change, the experiments referring to pipelines of 100 mm diameter and over give the mean arithmetical value of the diaphragm discharge coefficient and its mean-square errors, which are shown in Table 3.

TABLE 3

Modulus m	Reynolds' limiting number $Re_{lim} \cdot 10^{-4}$	Number of experimental points n	Mean value of the basic discharge coefficient α	Mean-square error of the value of αS_{α}%	Mean-square error of a number of measurements S_{α}^{α} %
0.35	11	25	0.645_4	0.05	0.23
0.4	13	14	0.659_0	0.12	0.42
0.5	18.5	30	0.692_0	0.04	0.24
0.6	24	34	0.738_6	0.06	0.33
0.7	30	39	0.801_8	0.09	0.59
0.75	33	24	0.843_1	0.05	0.25
0.8	36	33	0.891_7	0.09	0.52

Comparison of the data in Tables 1 and 3 for moduli from 0.35 to 0.7 indicate that the values of the diaphragm discharge coefficients adopted at present for moduli of 0.4-0.6 exceed the corresponding experimental values.

The coefficients for moduli of 0.75 and 0.8 given in Table 3 are also considerably smaller than those obtained by Witte previously [4] (see Table 1).

Thus, the materials on the diaphragm discharge coefficients examined in this article obviously indicate that, despite the prolonged study of the diaphragm discharge coefficients in a number of countries, the estimation of this coefficient and its error are not reliable, thus, making the investigation of the discharge coefficients of restricting devices in precision discharge-meters by means of modern methods of experimental data analysis a pressing problem.

SUMMARY

1. The values of the diaphragm discharge coefficients which have moduli between 0.4 and 0.6 and are adopted in the national standards are higher than the corresponding experimentally obtained values.

The mean-square error of the mean value of the basic diaphragm discharge coefficient in the range of 0.35 to 0.8 moduli varies between 0.05 and 0.12%, and the mean-square error of a series of measurements varies between 0.23 to 0.59%.

2. The investigation of discharge coefficients of restricting devices in precision discharge-meters by means of modern method of experimental data analysis remains a pressing problem.

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ELIMINATION OF EXCESSES IN INSTRUMENT MAKING

B. N. Vorontsov

In recent years our instrument-making industry mastered the production and is manufacturing a sufficiently large number of precision measuring instruments, which are of as high a quality as the best foreign makes. New original instruments have been designed, which enlarge the scope of measurements in industrial laboratories. Such instruments include the contact interferometer PIU, instruments for checking the smoothness of surfaces (MIS-11, MII-4 profile meters), a unique measuring machine for checking guide screws, universal goniometer GS-5, clockwork profile projector, modernized optical dividing head (ODG) with a measuring accuracy of 10", and a number of other instruments.

All these instruments are required by our industry; they have been successfully tested and are used for technical measurements in production. For the application of these instruments in practice it is important to make accessories for them which extend the scope of the instruments, and to issue brief but well-written instructions which are clear to inspectors with training.

However, neglecting the operational requirements of the new instruments, the manufacturing plants are careless in supplying accessories for them. They supply instead attachments which nobody will ever use, and sometimes do not even point out in the operational instructions for what purposes some of the accessories are designed.

At the same time lacking the knowledge of the customers' requirements (or simply ignoring them), the manufacturing plants do not produce simple and necessary fittings without which instruments cannot be fully utilized. As the result of this, many costly accessories dispatched with the instruments in the regulation outfits are not used, and the funds spent on their production are completely wasted.

For instance, the regulation outfit for interferometer PIU-2 includes two additional tables which, according to the operation instruction, are designed for checking grade II end gages (additional corrugated table) and for checking calibers and details 150 mm in diameter (base table). Yet the manufacturing plant ought to know that PIU instruments are not used for checking block gages of a grade higher than III, and such checking is only carried out in grade I State Inspection Laboratories; whereas plants, as a rule, check with the PIU-2 instrument gages not higher than grade IV. Hence the additional corrugated table is never used in the work of either the State Inspection Laboratories or industrial establishments. Neither is there any necessity to check calibers and details with diameters up to 150 mm by means of the PIU-2 instrument, since the tolerances of articles of such dimensions make it possible to check them on a horizontal telescope caliper. Thus, both additional tables dispatched with the PIU-Z outfit are made without taking into consideration their actual requirement in operation and are destined to remain in perpetual storage.

The operation instructions for PIU-2 should contain a more detailed instruction on the use of the mirror when looking for the interference fringes which have disappeared, since this happens fairly often in practice. The manufacturing plant will have to develop a better way of finding fringes by means of an additional optical attachment, instead of recommending the use of a magnifying glass which is not included in the regulation outfit of the set.

The regulation outfit of the new measuring machine IZM includes a stand with a bracket for holding a caliper telescope, which is not mentioned in the operation instructions except that it is to be used with additional devices. What additional measurement the designers of the stand intended to make remains a mystery

to the users of the IZM, who are obliged, however, to buy this "pig in a poke." It is superfluous to stress the fact that a vertical stand should not be a regulation accessory to the machine and does not justify the money spent on it. In developing unnecessary attachments, the manufacturing plant at the same time does not trouble to supply the instrument with really indispensable accessories, without which it is impossible to use the machine even for measuring large end gages, the very purpose for which the machine was designed. Thus, reference gages of 1000 mm and over cannot be checked on the machine without additional attachments in the form of special stands, a table, etc. Each consumer plant solves this difficulty the best it can, spending considerably more money in making these attachments than the manufacturer would have spent in mass production.

The ODG outfit includes 11 additional attachments, and yet the base plate on which the ODG is mounted, and without which it is used very seldom, is not included in the regulation outfit. As a result of this, in many establishments ODGs lie unused waiting for their base plates to be cast.

Vertical and horizontal telescope calipers are widely used in technical measurements; no measurement laboratory can afford to be without them. Manufacturing plants, for some unknown reason, include in the regulation outfit to vertical telescope calipers such unwanted attachments as devices for checking wire, a bracket for stop pins, and the pins themselves, all of them making up a superfluous ballast and never used in measurements. The replacement of the round layout table (for checking reference gages) by runners for moving the gages along the table and the replacement of the smooth surface of the stage by a ribbed one was not at all advantageous. As the result of such an "innovation" the productivity of checking was halved and other inconveniences have arisen.

The stand with a movable rest is completely superfluous in the design of the horizontal telescope calipers, since it only hinders measurements (for instance, in checking rings of a large diameter). By omitting these details from the instruments the manufacturing plant would decrease the cost of production and improve the operational properties of the horizontal telescope calipers.

In the 20 years of its existence the telescope caliper has not had any constructional improvements, although some of its details could be improved. Thus, the horizontal shaft, instead of being made smooth, could be improved by threading it for mechanical displacement of the brackets, which is more convenient in operation. It would not be difficult to extend the range of measurement of internal diameters by modifying the guides.

Horizontal comparators IZA-2 designed to measure rules, measuring scales, spectrograms, etc., are not widely used in industry and their manufacture is economically profitable only in limited quantities. In the engineering industry, however, comparators are used for checking indicating gages with graduations of 0.002-0.001 mm by means of an additional very simple attachment. It would be advisable to include this device in the regulation outfit of the comparator.

At present both the State Inspection Laboratories and industrial measuring laboratories are greatly in need of reference scales for checking micrometer screws in measuring instruments. These scales are made in optical plants on individual orders and are very expensive. Yet these scales could be easily produced by instrument-making plants. The scales could be made in large quantities thus reducing their cost. Reference scales for checking Brinell microscopes are also required. Certain foreign firms supply each Brinell microscope with a special scale for checking the microscope. Why should not our own Brinell microscope manufacturing plants adopt this procedure?

The instructions supplied with goniometer GS-5 are too brief, since GS-5 differs considerably from the existing instruments by its design and application. The GS-5 goniometer outfit includes seven exchangeable eyepieces, a revolving head with a set of diaphragms, bias illuminator with a grid, and a mechanical slit: altogether ten optical components, different in their design and application. However, the exchangeable eyepieces are dealt with so briefly in the instructions that the purpose of five of them and of the bias illuminator with the grid is not explained. The negligence in compiling this instruction is completely inexcusable; it should always be remembered that properly compiled instructions determine to a great extent the speedy mastering and correct use of instruments and, vice versa, a wrongly understood method may lead to gross mistakes and sometimes to the damage of costly measuring instruments.

In order to eliminate all the defects listed above, the instrument making plants will have to establish closer links with the consumers, and collect and sort the experience gained in the use of the instruments, including the use of their accessories. Much depends on the initiative and insistence of the State Inspection Laboratories in

whose regions there are instrument-making plants. These State Inspection Laboratories must take the lead in daily investigations of the operational properties of measuring instruments and in the improvement of their design.

ORGANIZATION OF BASE LABORATORIES

P. U. Markov

Modern engineering plants possess a large stock of mechanical and opticomechanical measuring instruments, and this stock increases each year both in size and variety.

The lack of timely repair and adjustment of measuring equipment leads to the infringement of uniform measurements, reduces the life of costly instruments, and leads to their premature failure, thus resulting in material and technical losses.

Before the reorganization of industry, certain Ministries had their own base laboratories, which, in addition to other work, repaired and adjusted instruments in the plants of their own administration. Under this arrangement many plants were deprived of the required servicing.

Prior to the reorganization of industry, one of the difficulties in organizing territorial base laboratories whose functions would include the repair and adjustment of instruments, was the administrative separation of factories. Now that the industry is controlled by the Councils of National Economy, these difficulties have disappeared and the conditions are favorable for the establishment of such laboratories.

The Interchangeability Bureau of the Committee of Standards, Measures, and Measuring Instruments has prepared technical data for the organization of repair and adjustment bases in the economic regions, thus assisting the Councils of National Economy in their task.

In this contribution ("An outline for organizing repair and adjusting bases in economic regions") the technical foundations for the repair and adjusting work are correctly specified, but in addition to it organizational recommendations are also given, with which in our opinion it is difficult to agree completely.

For instance, the Councils of National Economy are recommended to form rather large units (comprising 8 districts of economic administration), which would be serviced by one repair and adjustment base providing the servicing of all the factories in this area. Such a grouping will complicate the organization of laboratories even if only for the sole reason that the Councils of National Economy are not subordinated administratively to each other. In addition, systematic servicing of the plants will be difficult. Engineering plants require constant repair and adjustment of instruments. Some of the plants of any Council of National Economy, by the very nature of the production, do not require the services of personnel highly trained in measurement techniques, yet periodic technical assistance is required even by these plants.

The Interchangeability Bureau proposes to organize repair and adjusting bases of two types, the second type to be organized in instrument shops. It is proposed to pay the mechanics-adjusters on the basis of piecework.

With this proposal it is also difficult to agree. The repair and adjusting work is too specialized and cannot be separated from the Central Test Laboratories of plants. The instrument shops will be unable to deal with this work with the required efficiency simply since this work is new to them.

The repair and adjusting work should be organized in a better equipped and staffed establishment, such as the Central Test Laboratory of one of the engineering plants of a Council of National Economy. The work of such base test laboratories (BIL) should include, in addition to their former functions, the servicing of plants with repairs and adjustments of instruments, technical guidance and assistance in mastering new measuring techniques, and continuous inspection.

The servicing by the BIL of a given Sovnarkhoz (Council of National Economy) district or other administrative areas is not advisable, since the servicing cannot be, owing to the distances involved, either systematic or continuous and would require additional travelling expenses.

The BIL of the plant, where it is organized, should be subordinated to the director or chief engineer of the plant, and the technical production department of the Sovnarkhoz.

The mechanics-adjusters should be paid on a time basis like the engineers and technicians, instead of being paid on a piecework basis; a bonus system of payment should be worked out for carrying out the work according to plan.

The mechanics-adjusters should, as a rule, have secondary education.

The treatment of BIL mechanics-adjusters as salaried personnel will improve the quality of repairs and make additional staff for ordering, costing, and inspection unnecessary; moreover, since the BIL repairs group will not be an independent administrative unit, no additional bookkeeping personnel will be required.

The serviced factories should supply a list of their instruments with an indication of the type and amount of servicing required annually according to the conditions under which the equipment is used. Having received such information, the BIL drafts the plan for servicing the plants and gets it approved in the technical production department or the engineering plants department of the Sovnarkhoz.

On completing the work the BIL presents, in the name of the plant where it is operating, a bill to the client factory, taking the overhead expenditure into consideration. Technical assistance, consultation, and assistance in mastering new inspection techniques rendered to the client plants can be included in the overhead expenses of servicing or paid for separately.

Other problems such as the training of the mechanics-adjusters, additional equipment for the base laboratories, etc., should be solved according to the recommendations of the Interchangeability Bureau of the Committee.

The organization of base laboratories proposed in this article is in our opinion, realistic, simple, and economical.

The Tomsk Sovnarkhoz has already organized in one of its plants a base laboratory on this principle, entrusting it, in addition to its repair and adjusting activities, with rendering technical assistance to other plants in mastering new means and methods of inspection.

Before the BIL was established, the factory test laboratory from which the BIL was organized consisted of three laboratory assistants, one mechanic-adjuster, one engineer for intricate testing, and one person in charge of the Central Test Laboratory. After it was reorganized into a BIL, its staff was increased by four mechanics-adjusters, and one engineer in charge of the technical assistance to other plants on questions of measurement technique.

With this organization of the BIL it was found unnecessary to have any auxiliary personnel, since all the people in the laboratory carry out their own technical work.

In its "Outline for organizing repairs and adjusting bases in economic areas" the Interchangeability Bureau gives a long list of opticomechanical equipment which should be serviced for repairs and adjustment. A wide range of mechanical lever-operated measuring instruments should be added to the above list, since some of the establishments have no means whatsoever of repairing and adjusting these instruments.

In order to facilitate the operation of the base laboratories it is necessary to organize the production of spare parts for the instruments in specialized plants and to supply the parts to the Sovnarkhozes in question.

IMPROVEMENT OF THE WORK OF ADMINISTRATIVE INSPECTION AGENCIES*

In his letter to the editorial board, L. Ya. Vyshkind (Leningrad) notes that with the present level of measurement techniques penetration into all the production processes it is impossible to talk about administrative inspection only for linear and angle measurements apart from other types of measurements. Side by side with linear and angle measurements, an important part is also played by electrical, thermal, mechanical, radiotechnical, and other measurements. Therefore in organizing the work of the administrative inspection agencies it is necessary to take into consideration all the types of measurement used at the establishment. It is on this basis that the guidance of the work of administrative inspection agencies in factories should be approached.

In L. Ya. Vyshkind's opinion the transfer of industrial laboratories to the control of the Sovnarkhoz, as proposed by B. N. Vorontsov, would inevitably lead to duplication of work by the corresponding agencies of the Committee of Standards, Measures, and Measuring Instruments.

In order to widen the functions of the test laboratories, and make them participate more closely in production, it would be more effective to make their participation in the development of technological processes obligatory as well as in preparation of drawings for measuring equipment which is being developed by the chief technologist's department. It is only by such means that it will be possible to check whether the measuring equipment is correctly assigned and whether it satisfies the required metrological accuracy of production. It would be desirable to have on the staff of the laboratories an experienced metrologist-designer for this purpose. The plant chief engineers and their deputies should pay greater attention to the work of test laboratories. It is no secret that often chief engineers of plants not only fail to guide the test laboratories' work, but do not even know the facilities which they possess.

The elimination of departmental barriers in industry will help the Sovnarkhozes to take the following measures, which would, to a great extent, assist the development of measuring techniques.

1. Establishment, on the basis of the existing scattered factory and regional design bureaus, scientific research institutes, etc., of one All-Union Institute for the Design of Measuring Equipment for various types of measurement, with branches in 2-3 large industrial centers. The activity of the institute should be coordinated with that of the institutes of the Committee of Standards, Measures, and Measuring Instruments. Industrial establishments which have qualified personnel, suitable production equipment, and specialize in certain types of measurement should be allocated as experimental bases for the institute.

2. Organization of base test laboratories at these plants.

The function of the base laboratories should consist in the following:

a) testing the first models of the newly developed measuring equipment and preliminary evaluation of them;

b) assisting factories in measurements when the required equipment is lacking in the factory laboratories;

c) technical consultation and information on particular types of measurements.

3. Organization, in large towns, of shops for general sale of measuring equipment and accessories.

In L. Ya. Vyshkind's opinion it is impossible to entrust the supervision of gages between regular inspections to foremen, as suggested by B. N. Vorontsov, since the simplest equipment by means of which it is possible to check gages at the bench can only be used for gages up to the 3rd grade of accuracy. It would be better to accustom the foremen and the workers, whose job it is, under the new organization of the technical inspection departments, to check the quality of production, to submit for inspection gages of various degrees of accuracy at the appropriate time to the Inspection and Test Points. If they fail to do it, the cost of production rejected due to worn gages will have to be borne by the workers.

L. Ya. Vyshkind notes that B. N. Vorontsov correctly raises the question of the formal requirement placed on certain types of instruments irrespective of the conditions of their use in production.

*A contribution towards the discussion of B. N. Vorontsov's article "Pressing problems in organizing administrative inspection" (Measurement Techniques No. 5, 1958) [See English translation].

S. G. Kagan (Leningrad) supports B. N. Vorontsov's suggestion that the industrial laboratories should better meet the needs and requirements of production. They should not only supervise the uniformity of measures, but also determine the possibility of using various measuring equipment and instruments and also special means in checking the quality of production. The test laboratories should not only determine the serviceability of instruments and measuring equipment, but should supervise their correct application, since incorrect use of serviceable equipment also leads to excessive scrap.

For tackling such problems, the test laboratories should have specialists acquainted with gage and measuring instrument testing and with the technology of engineering.

S. G. Kagan considers that B. N. Vorontsov's suggestion to revise completely the regulations for administrative inspection so as to define the rights and duties of test laboratories is correct.

The periods for inspection fixed by the Central Test Laboratories cannot fully guarantee the serviceability and accuracy of instruments over the entire period between the inspections. Production workers must supervise the efficiency of their gages and return them at the end of each shift to the store for checking by the test laboratory. This will reduce the scrap due to the gages remaining on the benches for a long time without checking.

The experience of the Gor'kii plants, which allow some of their workers to determine the periods of inspection of "their own" gages, should be checked at other plants.

It is necessary to proceed with the organization of base laboratories, especially for certain types of measurements.

INFORMATION

CONFERENCE ON THE MEASUREMENT OF MECHANICAL QUANTITIES

E. F. Dolinskii and P. P. Kremlevskii

The conference organized by the D. I. Mendeleev All-Union Scientific Research Institute of Metrology, Lonitopribor, and the Leningrad Hall of Science (13-19 June, 1959) was attended by representatives of scientific research institutes and industrial establishments of Moscow, Leningrad, Khar'kov, Novosibirsk, Sverdlovsk, and other cities.

The basic aims of the conference consisted in establishing the main metrological problems in the sphere of mechanical measurements, analyzing the possible ways of solving them and critically evaluating the work already done and the possibility of applying it in practice in industrial and scientific laboratories.

The work of the conference was conducted in six sections – mechanical (force and hardness), measurement of discharges, rheological, pressure measurements, vacuum measurements, and measurements of vibrations. This circumstance had a favorable effect on the work of the conference, since it provided the possibility of hearing all the submitted papers and holding exhaustive discussions on them.

The recommendations of the sections have been communicated to the organizations concerned.

The results of the work of each section are described below.

Mechanical Section

L. V. Smirnov (VNIIM). "Ways of decreasing the dispersion of hardness values obtained on reference gages." An analysis is made of the principle causes of dispersion, the effect of heat treatment, and the composition of the material. In the resolution on the paper the urgent necessity of changing over to a centralized manufacture of hardness gages is noted.

S. A. Smolich and N. P. Slavina (VNIIM). "Establishment of standard instruments for measuring hardness." Instruments of the Rockwell and Vickers type were designed in which the main sources of error common to conventional instruments were eliminated. The necessity of studying various conditions of loading was pointed out. In the resolution on the paper the necessity of making the GOST which defines hardness more precise was noted.

S. S. Stepanov (VNIIM). "Certain problems in the theory of hardness." The basic thesis: the hardness numbers are determined by the maximum plastic deformation work.

M. L. Kotochigova (VNIIM). "Reference 1st grade dynamometers up to 10 ton-wt of the VNIIM type." The accuracy of these newly designed dynamometers is evaluated by the mean-square error of 0.04%. In the resolution on this paper the necessity of raising the top measuring limit of reference 1st grade dynamometers is noted.

F. S. Savintskii (Sverdlovsk branch of the VNIIM). "Dynamometers with strain-gage transducers." Investigation of dynamometers with several parallel links showed that their mean-square error was of the order of 0.1%.

B. A. Vandyshev (Sverdlovsk branch of the VNIIM). "Production of standard equipment for checking twist-measuring machines." The newly made stationary equipment produces torque with a maximum error not exceeding 0.13%; standard portable manometers measure it with an error not exceeding 0.5%.

E. F. Nekhendzi (TsKTI). "The conditions of annealing constantan wire for precision strain-gage transducers." Investigations indicated the possibility of making constantan wire whose temperature coefficient is near to zero.

Rheological Section

G. A. Malyarov (VNIIM). "Viscosity of water at 20°C." The viscosity of water was established at 0.010035 poise. Removal of the air dissolved in water lowers the viscosity by 0.12%.

L. P. Stepanov (VNIIM). "Production of reference viscosimeters with a range of $10-10^4$ and $10-10^7$ poise." Their mean-square error amounts for the first instrument to 0.2% and for the second to 0.5%.

I. A. Stul'ginskaya (VNIIM). "Viscosity measurements at low temperatures." An apparatus with an automatic cryostat (down to − 60°C) was made. The results of absolute and relative measurements of viscosity at temperatures near which the liquid loses the properties of a Newtonian liquid are provided.

Measurement of Discharges Section

S. S. Kivilis (VNIIK). "Discharge coefficients of constricting devices." Interpolation formulas for determining the basic discharge coefficients of diaphragms and jets are given, and one of the values the diaphragm discharge coefficient is made more precise. It was recommended to include these findings in rule 27-54.

P. P. Kremlevskii (VNIIM). "Measurement of pulsating flow discharges." A new general criterion for damping pulsating discharges instead of the normally accepted Hodgson's number is indicated. The possibility of using the generalized criterion not only for gas, but also for liquid discharges is shown. The design and comparative efficiency of single, double and treble section filters are given. The section recommended to include the main findings of this work in rule 27-54.

V. L. Cheishvili (VNIIGS). "Determining the discharge coefficient of Venturi tubes." Measurements were made with a special apparatus by the method of the international committee. The section noted the importance of the work and recommended some additional investigations.

A. A. Shatil' (TsKTI). "Investigation of a throttle method of measuring dust discharges in pneumatic transportation." The newly developed method of measuring dust discharge is reported. The section noted the importance of the work and the advisability of continuing it.

E. A. Gershkovich (VNIIM). "Checking of slot gas meters types RS-25 and RS-100." The checking was made by means of calibrated tanks and reference gas meters. The considerable effect of the level and viscosity of the oil used in the gear box on the readings of the meter was noted. The section noted the desirability of further work in determining the possibility of using reference gas meters for checking.

P. P. Kremlevskii (VNIIM). "Measurement of large gas discharges and methods of checking large gas meters." The section considered as a pressing task the immediate construction at the VNIIM of a reference calibrated gas tank for measuring discharges up to 300 m^3/hr, which is required for investigating various methods of measuring large gas discharges and also of reference gas measuring equipment at the Stanislav factory.

L. N. Shonin (NIITeplopribor). "Differential manometers of a compensated type with a pneumatic output." The section noted the good characteristics (with respect to accuracy and speed of operation) of the newly developed instruments and indicated the desirability of developing nonmercury differential pressure gages with mechanical indicators.

B. P. Mikhailov (GIPKh). "Discharge meters for corrosive media." The paper includes the description of a new design electromagnetic and vane-tachometric type of discharge meter and of a discharge meter with a constant drop in pressure and magnetic transmission.

N. N. Buzhinskii (Nevkhimkombinat). "Vane-tachometric type discharge meter with an electric transducer." The instrument has been constructed for, and is successfully measuring, sulfuric acid consumption.

V. K. Rukavishnikova (NIITeplopribor). "Electromagnetic discharge meters." The construction of a universal electromagnetic type discharge meter is reported. The instrument has passed its field tests.

L. M. Korsunskii (KhGIMIP). "Investigation of an electromagnetic discharge meter." The work in determining the effect of the velocity characteristic of physical properties of liquids and electrical interference on the accuracy of electromagnetic discharge-meter readings is described. The section recommended to intensifying the work of construction and bringing into use of a reference discharge meter based on the electromagnetic principle.

A. S. Khimunin (NIFI-LGU). "Ultrasonic method of measuring discharges." The paper gives a systematic review of various ultrasonic discharge meters, including designs incorporating a correction for variations in the flowing liquid density. The section noted the desirability of investigating construction of a reference liquid and gas discharge meter based on the ultrasonic principle.

Pressure Measurements Section

E. F. Dolinskii (VNIIM). "A standard loaded-piston barometer." The paper analyzes the modern state of barometric measurements. It also gives results of the work conducted in constructing a loaded-piston barometer with a piston cross-sectional area of 5 cm^2, which raises the question of changing over to a new standard in barometric measurements. The section noted the great metrological importance of this work.

K. I. Khansuvarov (VNIIK). "A 1st grade reference loaded-piston barometer." This instrument, with a piston cross-sectional area of 1 cm^2, was tested exhaustively and its high accuracy of measurement ($\delta = 0.001\%$), simplicity of construction, and easy use were established. The section recommended the instrument for general use.

A. A. Chasovnikov (VNIIM). "A reference loaded-piston micromanometer." A reference instrument of the piston type with a range of 400 to 4000 mm of water column pressure was developed and constructed. The section noted the high accuracy of the instrument and recommended it for general application.

N. A. Gaevskii (VNIIM). "A project of an apparatus for checking power indicators and pi-meters." The equipment is based on an original principle of simulating variable pressures by means of spring transmitters of mechanical efforts to the piston of the indicator or the pi-meter.

Vacuum Measurements Section

M. A. Gulyaev (VNIIM). "Tasks of the VNIIM vacuum-measuring laboratory." The tasks of the laboratory are enumerated, including the most important one of constructing an apparatus for measuring pressures from 10 to 10^{-11} mm Hg. The results of the work done in 1958 were reported.

V. A. Ryzhov (VNIIM). "A set of compression-type VNIIM manometers for the range of 10 to 10^{-4} mm Hg." The newly developed techniques of producing and calibrating capillary tubes made it possible to construct a set of four manometers. The deviation of the capillary tube diameters from the mean does not exceed 2μ. The mean-square error of the manometers does not exceed $2.5 \cdot 10^{-4}$ mm Hg.

M. I. Driga (VNIIM). "A reference thermomolecular VNIIM manometer for the range of 10^{-4} to 10^{-7} mm Hg." The paper deals with the theory, calculations, and results of the investigation of manometers which used vertical and horizontal pistons (noninclined) designed for the range of 10^{-4}-$5 \cdot 10^{-7}$ mm Hg with the possibility of lowering the range still further.

A. V. Eryukhin (VNIIM). "The work of the laboratory for obtaining and measuring superhigh vacuum." The paper reports the results of work done in constructing three ionization gages on the Bayard-Alpert principle. The instruments are designed to measure pressures of 10^{-9} mm Hg.

A. M. Grigor'ev. "Methods and equipment for measuring superhigh vacuum." This paper reviews modern methods and instruments for measuring pressures of 10^{-12} to 10^{-13} mm Hg, and analyzes the sources of error. The effect of the background current and means of eliminating it are indicated.

L. P. Khavkin. "A radioactive plutonium ionization pressure gage." The possibilities and advantages of using plutonium in ionization gages are discussed. The results of the work in constructing a pressure gage type MR-2 for pressures of 100 to 10^{-2} mm Hg are given.

Measurements of Velocity, Acceleration, and Vibrations Section

V. L. Lassan (VNIIM). "Tasks of the VNIIM in the sphere of vibration measurements." The work of the

laboratory in measuring vibrations is described and prospects of its further development discussed. One of the main problems is the extension of the range of acceleration measurements in the range of 25 to 150 g and the decrease in the error of measuring the amplitude to the order of 0.1 μ.

V. S. Shkalikov (VNIIM). "A VNIIM apparatus for producing and measuring vibrations." The constructional peculiarities of the equipment are described and the results of its tests given. The equipment is designed to operate in the range of 10 to 1000 cps.

D. A. Kharin (Institute of Soil Physics of the Acad. Sci. USSR). "Measurement of structural vibrations by the MIKS method." Methods of measuring structural vibrations, mainly those of hydroelectric power station dams are described. The equipment developed for the purpose and the measuring technique are described.

V. L. Lassan (VNIIM). "An apparatus for measuring angular velocities up to 60000 rpm with an error of 0.01%." The results of the work in designing and constructing an apparatus by means of which it is possible to check almost all types of modern tachometers are given.

A. N. Burago (Stage Optical Institute). "An optical method of measuring acceleration at impact." This optical method provides measurements of impact accelerations not exceeding 25 g.

CZECHOSLOVAK EXHIBITION OF MEASUREMENT TECHNIQUES AND ELECTRONICS

The Czechoslovak Exhibition of Measurement Techniques and Electronics opened in Moscow at the Polytechnical Museum on June 30, 1959. The exhibition consists of some 350 exhibits of 62 instrument-making plants which comprise the KOVO export agency.

One of the main exhibits consists of an automatic vibration device "Turbo-4" which was awarded a gold medal at the Brussels International Exhibition. The device is designed to test for fatigue and analyze dynamically turbine blades, bicycle frames, various levers, etc.

Another interesting exhibit is the miniature electron microscope, produced by the Tesla plant in Brno, which was also awarded a gold medal at the Brussels Exhibition. This instrument provides a magnification of 10000 to 30000 and possesses a resolving power of 20 A. The weight of the instrument, which can be easily placed on a laboratory table, amounts to 130 kg.

Various electronic measuring instruments made by the Tesla plant are also shown at the exhibition; they include various standard signal generators, RC oscillators, universal ac and dc bridges, voltmeters, Q-meters, servicing instruments for radio and television repair shops, etc. Among these, instruments of outstanding interest are: a set of measuring waveguides for superhigh frequencies, an original cathode-ray oscillograph for simultaneous observation of processes in five different channels, and a nuclear particle counter VM353.

An important place at the exhibition is occupied by the Regula plant pneumatic instruments for automatic recording, control, and signalling of production processes, high quality gas analyzers, ring scales, manometers, discharge meters, level meters, etc.

A crane scale which operates with a special torsion electromagnetic transducer is of especial interest.

Among the electrical measuring instruments, a gaussmeter which utilizes Hall's effect is of special interest. The transistor element of the instrument's probe has the minute dimensions of 3 × 1.5 × 0.4 mm. The error of this instrument does not exceed 2.5%. Multicurve recording instruments using wide-chart recording are of interest.

Special stands for checking dc and ac pointer measuring instruments attract attention. A special section is occupied by instruments for the textile industry, such as meters for measuring the dampness of cloth and yarn, twist meters for threads, a break test machine for threads and yarn, etc.

Another part of the exhibition shows many articles produced by the Prague "Élektrochas" electrical watchmaking plant.

A separate hall contains the products of the Czechoslovak radio and thermionic industry.

THE COMMITTEE OF STANDARDS, MEASURES, AND MEASURING INSTRUMENTS

MEASURES AND MEASURING INSTRUMENTS APPROVED BY THE COMMITTEE AS THE RESULT OF STATE TESTS AND PASSED FOR USE IN THE USSR

(Registered in May-June, 1959)

Modulation meter, trade-mark IM-13, of the Gor'kii Sovnarkhoz. State Register No. 1252-59.

Measuring amplifier, trade-mark 28-IM, of the Vilnyus Sovnarkhoz. State Register No. 1253-59.

Tensile force testing machine, trade mark RTs-1, for measuring standard cement samples for destruction, of the Kemerovo Sovnarkhoz. State Register No. 1254-59.

Variable capacitor, trade-mark R-512, of the Kiev Sovnarkhoz. State Register No. 1255-59.

Portable wattmeters, trade-mark D-539, of the Kiev Sovnarkhoz. State Register No. 1256-59.

Rack-mounted ammeters, trade-mark M-309, of the Krasnodar Sovnarkhoz. State Register No. 1257-59.

Rack-mounted voltmeters, trade-mark M-309, of the Krasnodar Sovnarkhoz. State Register No. 1258-59.

Rack-mounted ammeters, trade-mark É-309, of the Krasnodar Sovnarkhoz. State Register No. 1259-59.

Rack-mounted voltmeters, trade-mark É-309, of the Krasnodar Sovnarkhoz. State Register No. 1260-59.

Current transformers of the single-turn through type with molded insulation, trade-mark TPOL-10, of the Sverdlovsk Sovnarkhoz. State Register No. 1261-59.

A battery roentgenometer for measuring gamma-ray doses, trade mark "Karagach-2" of the Moscow (city) Sovnarkhoz. State Register No. 1262-59.

An apparatus for testing soft magnetic materials, trade-mark U520, of the Kiev Sovnarkhoz. State Register No. 1263-59.

Mercury-in-glass thermometers, trade-mark SP-27, of the Moscow (regional) Sovnarkhoz. State Register No. 1264-59.

Transportable 3rd grade reference scale, trade-mark OR3, w/ interchangeable arms for ranges of 20 g, 1 kg and 20 kg, supplied with a set of 3rd grade reference weights in the range of 1 to 500 g (State Register No. 811), of the Byelorussian Sovnarkhoz. State Register No. 1265-59 replaces the formerly approved reference scale, trade mark OR3, State Register No. 231.

Commercial dynamometers, trade-mark DR-10 of the Moscow (city) Sovnarkhoz are combined with dynamometers DR-3 and DR-8 of the Moscow (city) Sovnarkhoz. State Register No. 1062-56.